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Improvement of kenaf yarn for apparel applications

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IMPROVEMENT OF KENAF YARN FOR APPAREL APPLICATIONS

A Thesis
Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The School of Human Ecology

by
Ting Zhang
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Table of Contents

Acknowledgements.....	ii
List of Tables	v
List of Figures	vi
Abstract.....	viii
Chapter1 Introduction	1
1.1 Statement of the Purpose	3
1.2 Hypotheses	3
1.3 Research Objectives	3
1.4 Justification	3
1.5 Definitions.....	4
Chapter 2 Review of Literature.....	5
2.1 Introduction of Kenaf	5
2.2 Uses of Kenaf	7
2.2.1 Traditional Use of Kenaf	7
2.2.2 Value Added Produces from Kenaf.....	7
2.3 Kenaf Fiber	10
2.3.1 General Properties of Kenaf Fibers	10
2.3.2 Separation of Kenaf Fibers	12
2.3.2.1 Mechanical Separation.....	12
2.3.2.2 Bacterial Retting	14
2.3.2.3 Chemical Retting	15
2.3.2.4 Sugar Cane Separation Method	16
2.3.3 Softening.....	18
2.4 Yarn and Fabric Processing	19
2.5 Mercerization.....	22
2.6 Bleaching	23
2.7 Analysis	24
2.7.1 Fiber and Yarn Properties	24
2.7.2 Properties of Kenaf Content Fabrics.....	26
2.7.3 Image Analysis	26
2.8 Summary.....	27
Chapter 3 Methodology	28
3.1 Introduction.....	28
3.2 Materials, Reagents, and Equipment	28
3.3 Experiment Design	29
3.4 Chemical Procedure.....	29
3.5 Mechanical Procedure	30

3.6 Analysis	31
3.6.1 Fiber Characterization	31
3.6.2 Yarn Characterization	32
3.6.3 Fabric Characterization.....	34
3.6.4 Statistical Analysis.....	35
Chapter 4 Results and Discussion.....	38
4.1 Kenaf Fiber Testing	38
4.1.1 Photomicrograph Comparison	38
4.1.2 Physical Properties of the Fibers	40
4.2 Kenaf Yarn Spinning	42
4.2.1 Blending Ratio	42
4.2.2 Carding Loss	43
4.2.3 Kenaf Yarn Spinnability	44
4.2.4 Kenaf Yarn Structure	46
4.2.5 Kenaf Yarn Strength	49
4.3 Fabric Properties	49
4.3.1 General Description	49
4.3.2 KAWABATA Testing	52
Chapter 5 Conclusions and Suggestions for Further Work	69
5.1 Conclusions	69
5.2 Suggestions for Further Work	69
References	71
Vita.....	77

List of Tables

Table 1	The chemical solution and boiling time of the treatments.....	29
Table 2	Physical Properties of Kenaf Fibers with Different Treatment.....	40
Table 3	KAWABATA Testing Data for the fabrics from open-end rotor spun yarns...	56
Table 4	KAWABATA Testing Data for the fabrics from open-end rotor spun yarns...	57
Table 5	MANOVA Testing Data-- Value of $p < 0.05$	58

List of Figures

Figure 2-1. Pictures of Kenaf Field.....	6
Figure 2-2 Structures of Kenaf Plant.....	6
Figure 2-3. Kenaf Fiber Image	11
Figure 2-4. Schematic of Stick Machine and Trash Master	13
Figure 2-5. Schematic of Tibly Cane Separator.....	17
Figure 2-6. Schematic of the Modified Card	20
Figure 3-1. Spinlab High Volume Instrument System	33
Figure 3-2. Instruments of Kawabata's Evaluation System	36
Figure 3-3. Shear: Hand Calculation	37
Figure 4-1. SEM image of kenaf Fiber with Three Treatments.....	39
Figure 4-2. Fiber Loss by Treatment and Blend Level.....	45
Figure 4-3. SEM pictures of cotton yarns from different spinning methods.....	47
Figure 4-4. SEM pictures of 25% kenaf blended yarns from different spinning methods	48
Figure 4-5. Kenaf/Cotton Blend Yarns Strength Properties	50
Figure 4-6. Structures of Fabrics Knitted from Ring Spun Yarns and Open-end Rotor Spun Yarn	53
Figure 4-7. Bending Properties of Kenaf/Cotton Fabrics with Different Blending Ratio.	61
Figure 4-8. Shear Properties of Kenaf/Cotton Fabrics with Different Blending Ratio	61
Figure 4-9. Surface Properties of Kenaf/Cotton Fabrics with Different Blending Ratio .	62
Figure 4-10 Tensile Properties of Kenaf/Cotton Fabrics with Different Blending Ratio.	62
Figure 4-11 Compression Properties of Kenaf/Cotton Fabrics with Different Blending Ratio.....	63

Figure 4-12 Bending Properties of Kenaf/Cotton Fabrics from Kenaf with Different Chemical Treatment	63
Figure 4-13 Shear Properties of Kenaf/Cotton Fabrics from Kenaf with Different Chemical Treatment	64
Figure 4-14 Surface Properties of Kenaf/Cotton Fabrics from Kenaf with Different Chemical Treatment	64
Figure 4-15 Tensile Properties of Kenaf/Cotton Fabrics from Kenaf with Different Chemical Treatment	65
Figure 4-16 Compression Properties of Kenaf/Cotton Fabrics from Kenaf with Different Chemical Treatment	65
Figure 4-17 Bending Properties of Kenaf/Cotton Fabrics from Yarns with Different Spun Method	66
Figure 4-18 Shear Properties of Kenaf/Cotton Fabrics from Yarns with Different Spun Method	66
Figure 4-19 Surface Properties of Kenaf/Cotton Fabrics from Yarns with Different Spun Method	67
Figure 4-20 Tensile Properties of Kenaf/Cotton Fabrics from Yarns with Different Spun Method	67
Figure 4-21 Compression Properties of Kenaf/Cotton Fabrics from Yarns with Different Spun Method	68

Abstract

The objectives of the research are to determine the impact of the retting methods and blending percentage on the properties of kenaf fiber as well as the yarns and fabrics that contain kenaf, and to analyze and characterize kenaf fiber and yarns and fabrics that contain kenaf in terms of physical properties, such as tensile strength, elongation, evenness, absorbency and surface characteristics. In this research, kenaf fiber bundles were treated by chemical methods and softened to improve fiber properties. The treated fibers then were blended with cotton having 0, 10%, 25%, and 50% blending ratio and spun into yarns with open-end rotor spinning and ring spinning. These yarns were knitted into fabrics. Comparative analysis of the kenaf fiber in terms of fiber length, fiber fineness, and fiber strength was done by Uster HVI, Uster Tensorapid, and Scanning Electron Microscopy (SEM) techniques. The yarns were tested by Uster and SEM to determine their strength, elongation and structure. Properties of the fabrics were tested by KAWABATA System. It was found that after the chemical treatment, the fiber fineness, softness and elongation at break were improved, but the fiber bundle strength and length were decreased. Increasing the concentration of sodium hydroxide weakened the fiber strength significantly. To the yarns, the more the kenaf contained, the weaker the yarn and the fabric strength were, and the lower elongation the yarn and fabric have also. Fabrics became stiffer when kenaf blending ratio was increased. Open-end Rotor spun yarn and fabric exhibited a more even apparent but both were weaker than Ring spun yarn and fabric.

Chapter1 Introduction

Currently, one of the major challenges in the textile industry is a related environmental problem. Textile industries are facing great pressure to reduce pollutant emissions. This drives textile manufactures to seek new approaches to producing environmentally friendly products, such as recyclable and biodegradable textile materials. More and more attention has been drawn to agricultural products, wastes, and derivatives because of their renewability. One of the crops being investigated is kenaf, an old crop with many uses. The idea of making fabrics from kenaf has been practiced since the early 1990s. But the quality of kenaf fabric is not yet good enough for making apparel. This project will help develop and refine methods of improving kenaf processing for textile applications.

Kenaf is an annual crop that is native to Africa. Kenaf is being investigated as an alternative crop for farmers in many states in the U. S., including Louisiana. Many end-use products made from kenaf, such as canvas, animal feeds sacking and bedding, paper, fishing net and potting media ^[1]. The kenaf plant has two fiber types: the outer bark or bast portion (40% of the plant) and the inner woody core material (60%) ^[2]. There are many advantages of using kenaf fiber. Because a technology of separating kenaf core and bark has been developed, there is a possibility of using the entire kenaf plant or its separated parts. The bast fibers offer the advantage of renewability and biodegradability that is essential for making environmentally friendly textile products. Kenaf production is less costly and less time-consuming than other raw crops, given that it produces a high yield with minimal use of chemicals ^[3].

Traditionally, bast and leaf fibers, especially jute, abaca, pineapple, and kenaf, have been used for products, such as ropes, twine, and burlap. But natural fibers have become more prevalent in fashion over the last decade. Bast natural fibers used for apparel applications include ramie and milkweed fibers. They provide new aesthetic and physical properties, such as high moisture regain, rendering the fabric being more comfortable. Recently, jute and pineapple fibers have also been blended with polyester or cotton and made into coarse fabrics. If processed properly, kenaf is more lustrous, has greater tensile strength, and has greater resistance to rot when compared to jute.^{[4][5]} It is shown that kenaf has become a potential natural fiber source for both apparel and industrial applications.

Research on kenaf fiber include the following: production and softening of kenaf fibers, fabric production, characterization of the woven fabrics, production of non-woven fabrics from kenaf, and development of products, such as furniture under lays, carpet backing, and wall covering.^{[6][7]} However, because of the coarseness and stiffness of the fiber bundles, kenaf processing remains problematic. Also, kenaf single fibers are too short for textile processing. These unfavorable properties have inhibited the production of higher-quality yarns and fabrics that contain kenaf. Another problem is that raw kenaf bast fiber bundles are too coarse and brittle to process through conventional textile equipment.

Work has been done to develop methods for processing kenaf fibers. Investigation of differences in fiber quality of kenaf varieties has been conducted. Various treatments for obtaining soft and pliable fibers were screened and tested to determine the best process for large-scale production.^[8] Current research on kenaf is dealing with fiber

characterization, fabric performance and consumer acceptability of the fiber. But work on yarn characterization and modification is limited.

1.1 Statement of the Purpose

The purpose of the research is to investigate effects of fiber extraction methods on yarn spinnability and fabric quality of kenaf.

1.2 Hypotheses

- Increasing either the concentration of NaOH or treatment time will weaken the kenaf fiber.
- Increasing the kenaf content will weaken the kenaf/cotton blended yarns and fabrics and make them more hairy in appearance.
- Open-end rotor spinning will produce more even kenaf/cotton blend yarns than Ring spinning.

1.3 Research Objectives

- Determine the impact of the retting methods on the properties of kenaf fiber.
- Determine the impact of the blending percentage on the properties of the yarns and fabrics that contain kenaf.
- Aanalyze and characterize kenaf fiber and yarns and fabrics that contain kenaf fiber in terms of physical properties, such as tensile strength, elongation, and surface characteristics.

1.4 Justification

The procedures for yarn production were well developed for cotton. Physical properties of kenaf differ from those of cotton. For example, kenaf fibers are very short and therefore have to be spun in bundles. Also kenaf fibers are coarser and more brittle

than cotton. So it is necessary to blend kenaf with cotton in order to be able to use the spinning machine, which is designed for longer and stronger staple fibers.

1.5 Definitions

Kenaf -- an annual plant considered to be an alternative fiber crop. It resembles jute, but it is more lustrous and has greater tensile strength and greater resistance to rot.

Retting – a wet process by which the bundles of cells in the outer layers of the stalk are separated from nonfibrous matter by the removal of pectins and other gummy substances.

Mercerization -- the treatment of fabrics or yarns with an alkali. The alkali causes the fiber walls to swell and become round, thus increasing in strength, luster, and absorbency.

Spinning -- the process of obtaining a yarn, using the rotation movement and the difference in spin velocity of several shafts.

Twisting – the process for refining. Depending on the nature of the application, the emphasis is on an improved symmetry of the yarn, a specific yarn structure, an increase in the strength of the yarn or a combination of different colors and materials.

Tenacity --a unit used to measure the strength of a fiber or yarn, usually calculated by dividing the breaking force by the linear density.

Yarn Tex -- yarn fineness. It is the weight in grams of 1000 meter of yarn.

Chapter 2 Review of Literature

Kenaf is an ancient crop and has a long history of being planted and used by human beings. It was considered as an alternative crop and the products from it were simple and cheap. Because of its biodegradability and environmental compactability, the usage of kenaf has increased. The purpose of this project is to improve the kenaf fiber quality, so it can be used in apparel industry. The literature review will include an introduction to kenaf, usage of kenaf, extracting, processing, and mercerization of kenaf fiber, and the analysis methods used in previous experiments.

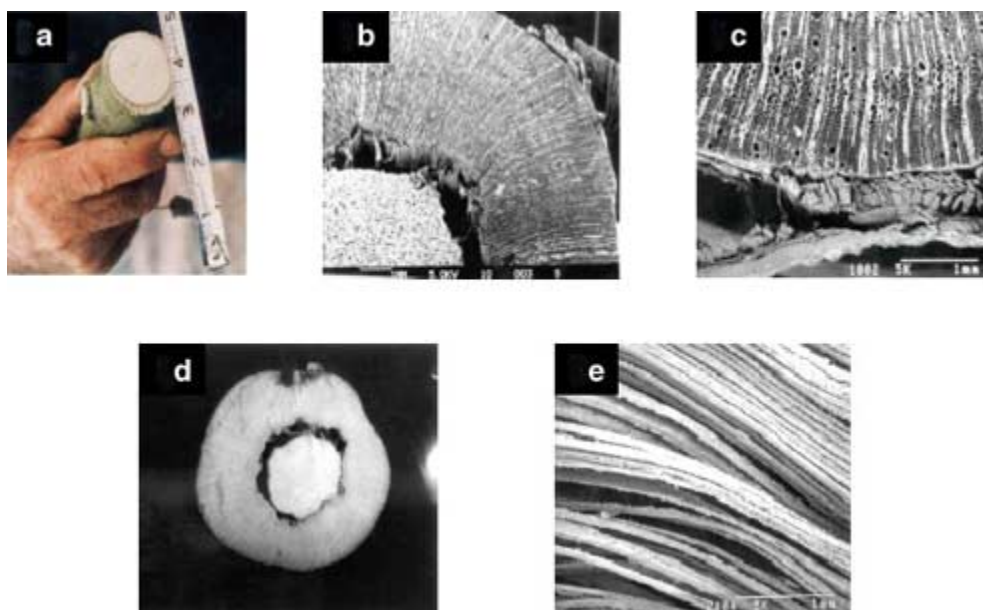
2.1 Introduction of Kenaf

Kenaf is a 4000-year-old crop that is native in ancient Africa. It is a member of the hibiscus family (*Hibiscus cannabinus L*) and related to cotton and jute ^[1]. Kenaf is a warm-season annual row crop well suited to the South and West of the United States, including California, Mississippi, Texas, Georgia, Louisiana, Kentucky, and Tennessee ^[2]. Kenaf was first introduced to the United States on a commercial scale in the early 1940s as the jute fiber imports were cut off as a result of World War II ^{[4] [5]}.

Kenaf has a single, straight, unbranched stem consisting of two parts: an outer fibrous bark and an inner woody core. Kenaf grows quickly, rising to heights of 12-16 feet (4-5m) in a 4-5 month growing season and 25-35 mm in diameter ^{[9][10]}. The core is the spongy tissue pith below the bark of the plant ^[4]. Figure 2-1 shows the kenaf plant and its intersection. Raw kenaf fiber is obtained from the outer bark. To affect kenaf fiber turnout, many agronomic practices can be manipulated; one method to increase the bast: core ratio of kenaf is increasing planting density.



Figure 2-1 Pictures of Kenaf Field ^[10]



- a. Kenaf Stem Showing Bark, Kenaf Bast Fiber and Core Fiber
- b. Kenaf Stem: Bark, Bast & Core Fiber x10
- c. Cross Section: Bast & Core x30
- d. Kenaf Core Cross Section, Stem without Bark and Bast Fibers
- e. Kenaf Bast Fiber x40

Figure 2-2 Structures of Kenaf Plant ^[12]

2.2 Uses of Kenaf

2.2.1 Traditional Use of Kenaf

Kenaf has been cultivated in Egypt since around 4000 B.C. China also has actively developed this plant and now is one of the largest kenaf producers in the world. Kenaf has been used for thousands of years mainly to make cordage, rope, burlap cloth and fish net due to its rot and mildew resistance ^[1]. Today, one of the major values of kenaf is used on a limited scale to produce pulp and paper in some countries as the substitute for wood ^{[5] [10]}. Kenaf offers many significant advantages in this application, including a short harvestable period and no chlorine bleaching. Kenaf paper is stronger, whiter, longer lasting, more resistant to yellowing, and it has better ink adherence than tree paper ^{[11] [13]}.

2.2.2. Value Added Produces from Kenaf

The stock of kenaf can be used almost entirely. Kenaf leaves and stems have a potential as livestock feed. Dried leaves contain 30% crude protein ^[4] and are used as vegetables in some part of the world. In recent years, with increasing concerns for environmental protection, kenaf has found more applications. The breakthroughs and advances in environmental technology have resulted from intensive testing and research in the kenaf industry. Here are some examples:

- **Natural Fiber/Plastic Compounds**

Natural fiber/plastic compounds, based on kenaf, can replace glass-reinforced plastics in many applications, such as automotive industry, packaging, and construction/housing. The compounds have the mechanical and strength characteristics of

glass-filled plastics but are less expensive and, in many instances, are completely recyclable ^{[12] [14]}.

- The Automotive Industry

The 1996 Ford Mondeo (sold abroad) features interior automobile panels made of kenaf fiber. Kenaf International supplies the fiber, which is processed by the supplier to Ford. The company expects that sales to European automobile manufacturers will steadily increase, as the industry becomes comfortable with the product and the kenaf products from KII Automotive Group are capable of meeting required demand ^[15].

- Construction & Housing Industry

Kenaf/plastic compounds, molded into lightweight panels, can replace wood and wood-based products in many applications. This product has the potential to be the first economically priced plastic lumber that can be engineered for use as building materials in housing industry ^[16].

In some cases, emphasis has centered in the utilization of core of the plant. Kenaf core has been used as packaging material, animal bedding, oil sorbents, and poultry litter.

- Food Packaging Industry

Pellets made from a kenaf/plastic compound can be molded into commercial food storage containers and virtually any other product now made of plastic.

Non-food related packaging opportunities are also numerous, including bulk chemical and pharmaceutical packaging; parts packaging in the electrical and electronics industries; and disposable packaging for large consumer appliances. In every instance, fiber composites have distinct technical and/or pricing advantages over plywood and/or cardboard -- and are recyclable, as well ^[17].

- Oil & Chemical Absorbents

The core is very absorbent and one of its main uses is to clean up oil spills and similar chemicals. One unique feature of Kenaf Absorb is that it absorbs oil before taking on water; once oil is absorbed, the product floats on the surface, which makes collection easier. This product is also non-toxic, non-abrasive and is more effective than traditional remediants, like clay and silica. This product is distributed by Fisher-Stevens, Inc., for use in Texas oil fields, but the product also absorbs gasoline, diesel, transmission fluid, and coolant spills.

In addition to use by individuals for personal garages, bulk applications include: clean-up operations in refineries, utility companies, land and sea spills, oil rigs, industries that handle bulk storage terminals; and for military field refueling applications ^[18] ^[19].

- Animal Bedding & Poultry Litter

Kenaf Bedding is sold in bags to farm and ranch supply stores and in bulk to large buyers, such as stables, zoos, and poultry farms. This product has superior absorbency, requires fewer changes, is cost competitive with most traditional litter and bedding products comprised of wood shavings, saw dust or shredded paper ^[20].

- Soil-free Potting Mix

This product competes with commercial potting soils and can also be custom-mixed for different horticultural applications. KII has a long-term supply arrangement with a nursery products wholesale business, Kinney Bonded Warehouse, based in Donna, TX. Their "K-Mix" product, a blend of kenaf and peat moss, competes with commercial mixes containing mostly peat moss or pine bark. KBW has a facility located adjacent to the kenaf processing facility on the Kenaf Ranch ^[21].

2.3 Kenaf Fiber

2.3.1 General Properties of Kenaf Fibers

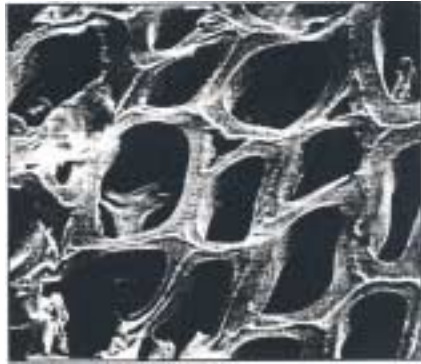
Raw kenaf fiber obtained from outer bark, is actually a bundle of lignocellulosic fibers. The fiber bundle size depends on the number of ultimate cells in each bundle. Most lignin is present between the ultimate cells. Kenaf contains approximately 65.7% cellulose, 21.6% lignin and pectin, and other composition. Lignin must be extracted to separate the fibers ^{[22] [23] [24] [25]}.

The physical dimensions of the fiber is one of the most important factors in apparel industry. Kenaf single fibers are only about 1-7 mm long and about 10-30 microns wide thus too short for textile processing ^[3]. A specific average length is not used because of the wide variability in the samples studied. Figure 2-3 shows the photomicrographs of an individual kenaf fiber and fiber bundle ^{[4] [26]}. These are coarse, brittle, and not uniform compared with cotton fiber, which makes them hard to process with conventional textile or nonwoven fabric equipment. The Instrumental methods for grading cotton fibers do not quite suitable to apply to kenaf fiber bundles ^[24]. These unfavorable properties also have inhibited the development of higher-quality wovens or nonwovens containing kenaf fibers.

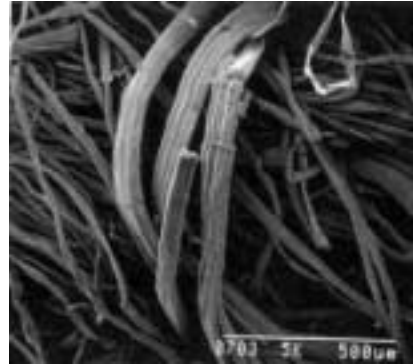
The measurement of single fiber dimension can be achieved by various methods. A large part of these differences is probably due to such factors as cultivars, location, and climate, besides the differences in the techniques used for analyses. In addition, fiber characteristics are also probably dependent on the maturity of the plant.

The most economical process is projection the image from a microscope on a wall or on a board, so the fiber dimension can be measured manually or by a digitizer. By

using an electronic indicator, digitizing can be achieved by identifying both ends of the fiber ^{[27] [28]}.



Kenaf fiber Cross-section 3000 ×



Kenaf fiber bundles

Figure 2-3. Kenaf Fiber Image ^[4]

The cellular structure of kenaf can be separated using dissociation method. The target plant is treated with chemicals that can dissolve the middle components and allow the fibers to become separated from one another. In some types of plants, the mild maceration process will not completely dissociate to a single fiber unit, resulting in an aggregate of fibers. These aggregates of fibers have the appearance of a single fiber. There are many kinds of dissociation methods. The solvent used in Schulze's (1857) method is a combination of various concentration of nitric acid with a small quantity of potassium chlorate. The mixture is allowed to stand at room temperature or is heated slightly to initiate the reaction. Jeffrey (1917) proposed a widely know alternative method for milder treatment. The solvent is a mixture of equal portions of freshly combined 8 to 10% nitric acid and chromic acid. Maceration at a cold temperature often gives best results, but the mixture may be warmed slightly to haste the reaction ^{[27] [29]}.

Generally speaking, the lengths kenaf fibers are shorter at the bottom of the stalk and longer at the top. The increase in length from the bottom to the top was not gradual, but S-shaped. There is more variation of the fiber length at the top of the stalk. Also, the longest fibers are located at the top. On the other hand, different parts of a plant have different chemical and physical properties. That is, the chemical composition and fiber properties of plant tissue taken from the roots, stem, trunk and leaves are different. And the chemical composition and fiber properties of plant tissue are also different at different stages of the growing season ^[30]. Fiber length increased in the early part of the growing cycle, and then decreased again as the plant matured ^{[29] [31]}. This may be an advantage in harvesting fiber at some time earlier than from a mature plant.

2.3.2 Separation of Kenaf Fibers

The process of separating the long and short fibers depends on the method of harvesting. In frost-free regions, the kenaf stalk is cut while green with special equipment. In cooler regions, the plant is typically frost killed and a natural drying of the stalk occurs, making harvesting with conventional farm equipment possible. The separation equipment is designed to accommodate the raw material in either whole stalk or chopped ^[32].

2.3.2.1 Mechanical Separation

There are many methods to separate the kenaf fibers. Mechanical separation of fiber is a quite economical way. The bast kenaf fibers that separated most of the core material are feed to the Rando Cleaner, a roller-type cleaner equipped with fine saw-tooth wire. There are two kinds of Rando cleaner, stick machine and trash master. Standard stick machine equipped with three 35.56-cm-diameter saws with and without Pelxiglas. The

trash master is a six-cylinder incline cleaner with 1.27cm space between grid bars and the degree of incline may be different, for example, 30° or 45°. Figure 2-3 shows the standard stick machine and 30 degree trash master. In order to get the cleanest fiber, it is necessary to process the bast fibers through both stick machine and trash master that equipped with different saws and incline degree^[4]. But the mechanically separated fibers were too stiff for processing into yarns^[33], so other methods for kenaf fiber separation need to be developed.

In the procedure of separating kenaf into its two fraction, moisture content is a significant predictor of final fiber content, in this case, moisture content of whole-stalk kenaf and humidity of ambient air need to be tested carefully. Type and number of



Figure 2-4. Schematic of Stick Machine and Trash Master^[4]

separation machinery should also be considered, for they decide the separation efficiency and processing rate, the two very important parameters. By using drying or separation during periods of low ambient humidity separation efficiencies of 95% to greater than 99% can be obtained. Whole-stalk kenaf above the moisture content of about 18-20% is

difficult to separate. Separation efficiency is low when the ambient humidity is above 60% and must be accomplished with the aid of drying ^[31]. The stick machine is more efficient at fiber and core separation than the 6-cylinder cleaner. The slower process rate can also increase separation efficiency ^[34].

2.3.2.2 Bacterial Retting

Bacterial retting also can be called natural retting. This is done first by decorticating the kenaf with a splitting machine, then retting the kenaf stalk in open troughs. Water temperature is monitored and maintained at 30 ± 2 °C throughout the process. Staggered retting is the best method for obtaining uniform fibers with immersion of the bases of stalks initially and then the whole stalks. This method is used to prevent over retting of the upper stalk portion. The retting process takes from 5 to 22 days. Then the stalks are washed in hot tap water to remove the remaining shiny, slippery, and green slime residue. And the product is air dried and combed with a soft brush to obtain fibers ^[35].

Retting is commonly carried out for flax. It is a biological process, depending on fermentation by anaerobic bacteria or dew-retting by aerobic fungi. Compared with flax, kenaf fibers are highly lignified and are tightly bound in a lignified bundle. Lignin occurred by 30 day after planting (DAP) in kenaf bast, and little change occurred beyond 60-90 DAP ^[26]. Lignin is a very recalcitrant natural material that resists microbial degradation by most organisms, only the white rot fungi, a noted group of microorganisms, can degrade this compound. And the senescent material can be extremely recalcitrant to biodegradation (retting) due to the production of lignins. In most cases, kenaf is allowed to grow until it is killed by cold weather, and then the kenaf

is left to stand for some time for on-the-stalk retting. Fiber from an immature juvenile plant is low in lignin, making it more suited for processing since there may be advantages in reduced chemical and energy consumption during product processing. So harvesting kenaf earlier than full maturity and perhaps before the cell walls are fully lignified is necessary, because the earlier harvested plants may provide bast ribbons with less lignification so fibers could be better retted. While early harvesting may lead to a lower yield, so there may be possible to harvest two crops in one season to give the same yield of fiber but with much less lignin ^[27].

Bacterial retting is a simple and inexpensive process commonly used to separate bark fibers and reduce the size of fiber bundles for use in textile processing. The natural retting process is lengthy, but the resulted fibers have many desirable characteristics. However, this retting method causes environmental problems, it gives very bad smell during the retting, and therefore, other retting methods using chemicals were developed.

2.3.2.3 Chemical Retting

To perform a chemical retting the fibers are soaked along the entire length in 0.85% Triton X-100 (used as wetting agent) at a fiber-to-liquid (w/v) ratio of 1:10 for one hour. Then the barks are removed and immersed in 7% NaOH and 0.5% sodium bisulfate (NaHSO_3) (w/v) solution, and with this the fiber-to-liquid ratio is increased to 1:20. Adding NaHSO_3 is aimed to prevent strength loss in the fibers. This solution is boiled for one hour, with the fibers submerged in it. The fibers are then removed and washed in hot tap water until the water runs clear. Then the fibers are submerged in a 0.2% acetic acid (v/v) solution for two minutes. The neutralized fibers are washed thoroughly in hot tap water and finished with air-drying and combing the fiber ^{[34][36]}.

The chemical retting is a quicker process than the natural, but it affects several properties, including a loss in tenacity, color, and luster when compared to the bacterially retted fibers. When environmentally possible the combination of the two methods can reduce the retting time without negative effects on fiber quality. Several ways were tried to improve the quality of chemical treatment and reduce the consumption of chemicals [37].

A modified chemical treatment was proved to extract and soften the kenaf fibers effectively. The degumming method that previously used for ramie process introduced [Cl⁻] to the treatment. The procedure involves: immersion in acid solution, boiling in NaOH solution of 14g/l for 140 minutes, bleaching with NaClO, and the concentration of the [Cl⁻] is 1.0g/l, washing with acid, rinsing in water, refining in NaOH and Na₂SO₃, washing in water, and air drying. The resulting fibers are finer and softer than the fibers from the ordinary chemical treatment [21] [38]. Adding enzymes also helps a lot in fiber extracting. The combination of chemical and enzymatic retting may improve retting and reduce costs. A mixture of chelators and enzymes, such as Ultrazym and Flaxzyme effectively retted stems [39].

2.3.2.4 Sugar Cane Separation Method

Because of the physical similarity of kenaf and sugarcane, a process initially developed for the extraction of fiber bundles from the rind of sugar cane has been used on kenaf. The biggest advantage of this process is that it is possible to reduce the size of fiber bundles in cross section, so the bundles can have sufficient length for textile applications. The process includes mechanical separation, chemical extraction, and steam explosion. By changing the extraction parameters, the final properties of the fiber

bundles can be controlled ^[40].

The mechanical separation is accomplished with the Tibly cane separator that separates the pith from the rind by longitudinal splitting and rotation actions. Figure 2-5 shows the Schematic of the Tibly cane separator. Billets of kenaf stalks are guided onto the splitter blade, which cuts the stalk into half shells. Each piece passes to a pith removing station, which has two rollers. The inner roller is equipped with blades, while the outer roller has spikes in order to guide the piece through this station. The removed pith falls through a chute and is fed onto conveyor. In commercial processes, the rind piece enters the next station, which removes the outer wax layer ^{[41][42]}.

Chemical retting here uses low concentration alkaline solutions, high temperature, and pressure. Mechanical agitation is involved in the reaction system. This mechanical agitation can also be used as a tumbling motion that is responsible for a preferential

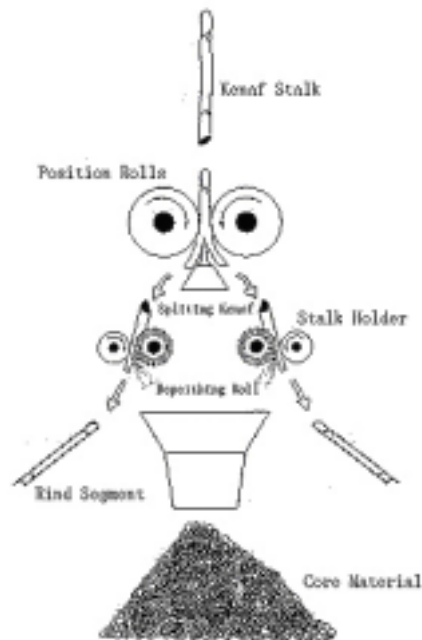


Figure 2-5. Schematic of Tibly Cane Separator ^[41]

reduction of cross-section rather than the length of the stalk ^[43].

In the third step, the kenaf fiber bundles are steam-exploded in order to further reduce bundle cross-sections. Live steam with the pressure as high as 0.7 Mpa is injected into the reactor and then the pressure is quickly released. The moisture in the fibers evaporates suddenly, blowing them apart into dry separated fiber bundles ^[44].

2.3.3 Softening

The kenaf fibers are still too stiff to spun after retting. They must be softened. The most commonly used method is chemical softening. The fibers are degummed by soaking in 0.3% HCl for 30 minutes, washing, and then boiling in 1% NaOH for 1 hour. The fibers are then scoured in 1% acetic acid and washed thoroughly in warm water and dried ^[45]. The fibers also can be softened using a commercial softener.

Treatment by batch emulsion has proved to be able to soften jute fibers. This is also tried to extract the kenaf fiber. The emulsion contains 22% vegetable oil, 1.5% sodium stearate, and 76.5% water. The fibers are soaked with fiber-to-liquid ratio of 1:10 for 5 hours under 127 Kpa pressure and the emulsion temperature is maintained at 90°C. Then the fibers are washed and air dried ^[46]. The fiber bundle size is reduced about 12%. The main function of the emulsion treatment is to soften fibers because the lignin is partially solved in the emulsion and water ^[24].

Enzyme treatments have been successful in softening cotton fabrics and theoretically may be effective on fabrics with kenaf fibers. Two kinds of enzyme: xylanase and laccase, were proved working. The fabric/enzyme liquor ratio was 1:80. The temperature was raised to 75 °C for 15minutes to denature the enzymes and the maintained 50°C during the 60minutes' laundering. The fabrics were then cooled down

at 25C for 15minutes, and rinsed ^{[39][47] [48]}.

2.4 Yarn and Fabric Processing

Research on fiber processing and characterization has significant implications. Retted fiber characteristics determine the feasibility of using the retted fibers for apparel applications.

The procedure for yarns spinning includes several steps. The most common processes are opening, carding drawing and spinning. Usually the fibers are packed as bales for shipment, so they need to be loosened and separated to make them easier for the following processes. By passing between feed rolls to a rotation beater, they can reach their maximum volume. Opening can also clean the fibers by removing dirt and other impurities. The heavier, unwanted trash, such as leaves, seeds, twigs and insects, are shaken and loosed from the fibers during the process ^{[33] [47] [51]}.

Then the fibers are sent for carding. Carding machines are the most important equipment to form fibrous web. Carding is aimed to further divide the fiber clumps with minimum fiber breakage and remove impurities and fiber entanglements. A carding machine consists of a set of cylinders (usually 4-7 number of cylinders) that have different diameter, rotating speed and rotating direction. The surfaces of the cylinders are full of saw-type teeth (needles) that make the fibers untangle and parallel with each other ^[52]. Carding can somewhat line up the fibers in one direction and remove the remaining trash and extremely short fibers. The product from carding is sliver, a rope-like array of fibers that are loosely held together ^[33]. In processing kenaf fiber, the carding machine needs to be modified in order not to break the kenaf fiber, since the kenaf fiber is coarser, longer, but weaker and more brittle than cotton fiber. Figure 2-6 shows a schematic of

one modified card ^[53]. After modification, the rotating speed is lower, and the distance among the needles is larger. The card that was originally equipped with 448 teeth/in² was reclothed (changed the teeth) with 270 teeth/in², and these teeth were longer and heavier to handle the heavier kenaf fibers ^[52]. During the carding process, several different fibers can be blended together to obtain uniform distribution. Variation among the natural fibers is a primary difficulty to spin them into yarns. In order to reduce the variation, several card slivers are combined together. This process is drawing. The resulted product of drawing is also called sliver. But the sliver is more uniform in size and weight.

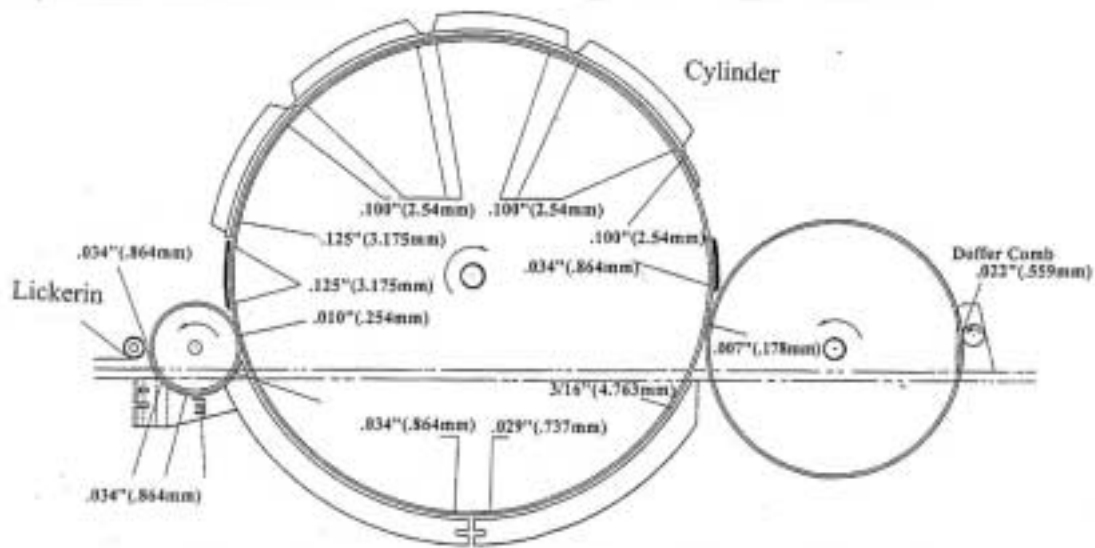


Figure 2-6. Schematic of the Modified Card ^[52]

A yarn is defined as a continuous strand of textile fibers, filaments or materials in a form suitable for knitting, weaving, or otherwise interworking to form a textile fabric ^[47]. Yarn has a direct impact on the quality of end-use products. Studies show that yarn

properties vary with the method of spinning. There are three major methods of manufacturing spun yarn. They are ring spinning, open-end spinning, and air-jet spinning [50].

Ring spinning must be coupled with a roving process. Roving actually is reducing the size of the sliver into a product that will be suitable for the ring spinning process. In ring spinning, a traveler system is the key part to twist fibers together. The traveler rotates faster than the yarn is fed from the front drafting rolls and so twist has to be inserted. The yarn is wound onto a bobbin and then has to be wound onto a larger standard package [32].

Open-end and air-jet spinning both can use drawing sliver as direct input and the finished yarn can be wound directly onto a ready to sell package. Rotor spinning is a method of open-end spinning. Twist is inserted to hold the fibers together inside a cone-shaped rotor (a high speed centrifuge). And the yarn is continuously removed from the end of the rotor. In air-jet spinning, an air nozzle is used to tangle the fibers into a yarn. The open-end spinning and air-jet spinning are more economical than the ring spinning. But the yarn strength is lower and yarn surface quality tends to be harsher. However, open-end spinning has fewer defects and air-jet spun yarns have superior evenness and a low tendency to pill [33].

There are other spinning methods, such as warp spinning, friction spinning, ply spinning, cover spun spinning, and self-twisting spinning. If blended with cotton, kenaf can be spun like other staple fibers using the cotton processing system. In recent years, a number of staple spinning processes have been developed to shorten the number of steps necessary for yarn preparation [47].

2.5 Mercerization

Textile fibers in the raw state are usually unsuitable for desired end uses. Finishes are applied to fibers to improve their properties. Cellulosic fibers, such as kenaf, cotton, jute, and ramie can be processed in similar ways because of their similar chemical composition^[54]. Mercerization is the treatment of fabrics or yarns, with an alkali. The alkali causes the fiber walls to swell and become round, thus increasing in strength, luster, and absorbency. Mercerization also enhances dyeability of cellulosic fibers. This process may be applied at the yarn or fabric stage^[53].

Mercerization can be achieved using sodium hydroxide or liquid ammonia. Sodium hydroxide treatment consists of immersing the yarns or fibers in a solution of NaOH (caustic soda) for short periods of time, usually less than four minutes. The material is then treated with water or acid to neutralize the sodium hydroxide. If the material is held under tension during this stage, it is kept from shrinking appreciably. If no tension is applied, the material may shrink by as much as one-fourth. The effect of NaOH was first discovered on cotton in 1844 by John Mercer. Liquid ammonia has been found to have inherent advantages over sodium hydroxide because it acts faster and is cheaper due to recovery of the reagent. This process has also been applied to other cellulosic fibers to improve hand (feeling of hand) and fiber strength^[54]. Tensile properties and extensibility of rotor-spun yarns were also improved significantly through mercerization^{[55] [56]}.

Kenaf is a relatively new textile material. Some mercerization has been done on kenaf or kenaf/cotton blend fiber. One experiment was done using American Association of Textile Chemists and Colorists (AATCC) Test Method 89-1994 in a completely

randomized design. Response of the yarns to tension mercerization was evaluated by the barium activity number. According to the test method, the barium activity number in the range of 100-105 indicates no mercerization, above 150 indicates substantial mercerization, and between 105-150 indicates incomplete reaction. Findings showed there was no mercerization for most of the yarns since the number was between 58 and 106. The test was developed for cotton, so this may partially explain activity numbers being lower than for cotton ^[57].

To solve this problem, another method was proposed. The principle of action was based on the use of shear deformations combined with pressure. It has been shown that under the conditions of plastic flow (movement of material under intense pressure) the fibrous high-yield semifinished product produced from woody plants, due to its specific structure, has better physicommechanical properties than that from the AATCC method. It has been established that under the conditions of high pressure, when cellulose interacts with hard alkali, alkaline cellulose is produced. This can be confirmed by X-ray analysis data. The depth of cellulose mercerization processes under the conditions of plastic flow does not depend on temperature ^[58]. The results showed that after treatment with enzymes, bleach and mercerization, these fabric blends became more aesthetically appealing and developed a soft hand ^[59].

2.6 Bleaching

The fiber bundles can be bleached, dyed and used for various textile applications. However, unlike other pure cellulosic fibers (such as cotton), kenaf contains a relatively high content of lignin (7.7%), hemicelluloses and other materials (pectin, waxes) in addition to cellulose. Therefore, it is expected that the bleaching and dyeing behavior

will be different as compared to cotton. Bleaching leads to loss in the tensile strength of the fibers, caused by partial removal of the non-cellulosic components that basically constitute intercellular binding materials ^[60].

The bleaching process was operated at Louisiana State University. Kenaf from Mississippi State University was processed two times through a mechanical cleaner and opener at USDA/SRRC in New Orleans ^[61]. The fiber bundles obtained were washed and then bleached with H₂O₂, according to a 2x2x4 factorial experimental design. The independent variables were temperature with two level (75C and 85C), time with 2 levels (2 hours and 3 hours), and peroxide concentration with 4 levels (4%, 6%, 8%, and 10%). These parameters were selected because milder conditions with longer treatment times are recommended for lignocellulosic fibers. Bleaching experiments were performed in a randomized order. In the batch of bleached fibers from each experiment, fibers were randomly selected and evaluated for tensile properties (strain, tenacity, and modulus), using an Instron tensile tester. The structural features of fiber bundles before and after bleaching were observed using an environmental scanning electron microscope ^[62].

Bleaching of kenaf results in white fibers, with a significant decrease in tenacity. However, other tensile properties as well as the linear density of kenaf are not significantly affected by the bleaching process. Also, in the bleaching process some of the encrusting materials, especially lignin, are removed from the kenaf ^{[61] [62]}.

2.7 Analysis

2.7.1 Fiber and Yarn Properties

Data was collected on the following characteristics: reed length, bundle breaking tenacity, elongation at break, color, luster, and residual gum content. Comparisons were

also made to determine if variety differences affected these fiber characteristics.

Reed length is the total length from base to tip of the decorticated kenaf stalk before and after processing. These criteria may be important for fiber yield when the intended use is for products, such as ropes and cordage.

Bundle breaking tenacity is defined as the load required to break a fiber bundle of fixed length and weight. The flat bundle method is believed to be a good indicator of yarn strength and has a high correlation to yarn quality index. Bundle breaking tenacity as a measure of fiber quality would provide quick, accurate results depending on linear density of the bundle. It establishes the possibility of extracting fibers for large scale production of fibers.

Elongation at break is the amount of stretch of a fiber bundle before it breaks. It is an important measure to indicate the ability to stretch.

Color and luster are important properties depending on the fiber end use. Luster has a positive correlation with strength.

Gum content refers to the total wax, oil, lignin, and other hemicellulosic material. Residual gum content, the amount of gum left after processing, affects the fineness of fibers. This ultimately determines the success of using these fibers in a fine, woven textile structure ^[64].

When the fibers resulting from chemical retting and bacterial retting were compared, the chemical retted fiber had less residual gum content, but the bundle breaking tenacity was lower and the color and luster were also not as good as the bacterial retted fiber. The elongation at break was almost the same. After carding, the residual gum content was decreased to a very low level, but the fiber length was much

shorter, which made the kenaf fiber much harder to spin. The study of the properties of kenaf fiber after mercerization is still limited ^[65]. The properties of the yarn and fabric were tested according the standard ASTM methods.

2.7.2 Properties of Kenaf/Cotton Blend Fabrics

Studies show that finer yarns and fabrics can be made using retted kenaf blended with cotton. But the kenaf fibers could not exceed more than 30% of the blend. After blended, the yarn strength was weaker, stiffer, and less recoverable than 100% cotton, but displayed very high air permeability ^[39]. Fabrics made of 50/50 kenaf/cotton in the filling direction and 100% cotton in the warp direction have been woven and compared with 100% cotton. Breaking strength, shrinkage, abrasion, and pilling resistance of the blended fabric were almost the same as the control fabric. Elongation at break and tear resistance were lower, but still pass the requirements for apparel applications ^[66]. But generally speaking, the fabric was not up to apparel quality because it was too harsh to touch. More research was needed to improve the softness of the fabric. The good tensile property and resistance to mildew and rot of kenaf may open up markets for industrial textiles ^[67].

2.7.3 Image Analysis

In order to understand the properties of textiles, surface properties need to be characterized. Recently, image-processing techniques have been used to evaluate the appearance and defects of fiber assemblies, such as slivers, yarns, and fabrics. Imaging techniques can be successfully used to obtain detailed information about fabric structure in the laboratory environment as well as in the production environment. Such evaluation has positive implications for measurement of textile quality during the production

process. Electronic images contain more visual information than the human eyes can discern. After a textile product is imaged, procedures may be used to yield more detailed structural conformation and to calculate several parameters ^[68] ^[69].

Yarn could be analyzed for characteristics, such as blend-irregularity and blending characteristics. Image analysis was used to study blend irregularity in blended yarns. The image analysis system enabled researchers to quantitatively evaluate the surface of blended staple yarns ^[57]. In the experiment that evaluated mispicks in woven fabric, image analysis was used successfully to study web characteristics of non-woven textiles ^[70]. Parameters such as web uniformity pore size, pore structures, and fiber diameter had also been studied ^[69]. This interesting new technique would be very helpful in textile processing. Evaluation of blend irregularity could be very important for production of kenaf blend yarns.

2.8 Summary

Kenaf's strength and resistance to rot and mildew make the cotton/kenaf fabric very unique in diverse end uses. Its good adhesion ^[71] because of its physical structure and its strength make it well suited for selected industrial applications. Fashion designers are always looking for novel interesting textures and textiles. Cotton/kenaf blends can provide a new texture for textiles to be used in apparel and home furnishing industry though spinning kenaf fiber is still a big problem that needs to be solved.

Chapter 3 Methodology

3.1 Introduction

Fibers extracted from kenaf were investigated as a new source for textile and geotextile industries. Structurally, the stalk from which the fibers are extracted consists of outside rind and inner pith. In the rind of the kenaf, the fibers are bonded in the middle lamella by lignin and other encrusting materials. In order to obtain the fibers, the lignin and binding substances must be removed. The extraction conditions significantly affected the amount of lignin removed and the proprieties of the fiber bundles obtained. The variables controlled were alkaline concentration of the extraction solution and extraction time. The physical properties of the fiber were tested. The kenaf fiber were also blended with cotton at different percentage to make yarn and fabrics, and their properties was tested and compared. The yarns were spun with both Ring Spin and Open-end Rotor Spin methods. This section presents the experimental methods used for degumming process, carding, spinning, and evaluation of the characteristics of fiber, yarn and fabric.

3.2 Materials, Reagents, and Equipment

Kenaf ----- bought from Mississippi State University. It was separated by a mechanical method.

NaOH -----sodium Hydroxide, Certified A.C.S.. Producer, Fisher Scientific.

NaHSO₃----- Sodium Bisulfite, Certified A.C.S.. Producer, Fisher Scientific. Assay (as SO₂): 66.4%. This product is usually a mixture of Sodium Bisulfite, NaHSO₃, and Sodium Metabisufite, Na₂S₂O₅.

HCl ----- Hydrochloric Acid, Certified A. C. S. plus. Producer: Fisher Scientific. Solution

Softener -----Snuggle (ultra) with color protection

Heater ----- Munsey Buffet Range. Model R92. 1650 Watts.

Oven ----- Producer: Blue M Electric Company. Model: POM-336C-1

3.3 Experiment Design

A completely randomized design with 3x4x2 factorial arrangement was used. Three chemical treatments with different concentration of sodium hydroxide and boiling time were used to extract the kenaf fibers. The treated kenaf fibers were blended with cotton at 4 different blending ratios: 100% cotton, 10%, 25%, and 50% kenaf. The kenaf/cotton blends were spun with the two spinning methods, Ring Spinning and Open-end spinning. To produce control samples, Acala cotton fiber was also spun into pure cotton yarn.

3.4 Chemical Procedure

Only Chemical retting was used in this project. The procedure involves boiling in NaOH solution—neutralization with acid—water washing---and drying with an oven. The concentration of sodium hydroxide and boiling time were the key factor affecting the treatment. Three chemical treatments were used in this study. The concentration of NaOH and boiling time is in the Table 1.

Table 1 The chemical solution and boiling time of the treatments

Treatment	NaOH %	NaHSO ₃ %	Time, hr
1	2	0.2	1
2	2	0.2	3
3	5	0.5	1

In all the chemical treatments, the fiber-to-liquid (w/v) ratio was 1:20. The fibers were washed thoroughly under the warm tap water after boiling, until the water ran clear.

Then the fibers were submerged in 0.3% HCl solution for 5 minutes for neutralization, and washed again.

After retting, the fibers were softened by soaking the fibers in using commercial softener, Snuggle, for one hour. The concentration of softener was 3.0 g/l, and the kenaf/water ratio was 1:10. Then the fibers were washed thoroughly with warm tap water and dried in an oven at 100 °C until dry.

3.5 Mechanical Procedure

The USDA Southern Regional Research Center (SRRC) has a Miniature Spinning Laboratory (MSP). It is equipped with a set of unique miniature textile machinery that can process small amount of fiber bundle (50g). Experiment of the kenaf yarn spinning was performed in the MSP. Acala cotton was first passed through a Kirkman Dixon opener to open and clean the cotton fibers. The appropriate quantities of cotton and kenaf were hand blended and cleaned by the opener again, then evenly blended in a Spinlab opener/blender. To minimize kenaf losses from the blends, a Whitin coarse-wired card was used. A pair of Medley drawing frames produced breaker and finisher slivers. Two kinds of spinning methods were used to produce yarns, Ring spin (R) and Open-end Rotor spin (OE). Ring spun yarns were spun on a Shirley sliver-to-yarn machine. A Suessen spin tester was used to spin Open-end Rotor yarns.

The yarns were knitted on a small diameter Lawson-Hemphill FAK knitter. Accommodation was necessary to facilitate knitting of the kenaf-blended yarns. Sometimes, a tensioning restraint was used to prevent the twist-lively yarns from snarling. Hairiness of the yarns may provide adequate resistance to constrain the yarn as it fed off the supply cones. The yarns were knitted with a 3-inch diameter, 160-needle

cylinder with a 3.4 meter head, an 8/1 ratio, 14.9 cut at 60 PRM, and 27.3 courses/inch, for a tightness index of 15.

3.6 Analysis

3.6.1 Fiber Characterization

In order to examine the physical characteristics of the fibers, a scanning electron microscope (SEM) was used. The SEM allows examination of specimens without coating and drying and also enables the observation of structural changes in textile materials under different conditions, such as wetting and heating. The fiber bundle pictures may help to compare the difference of the three chemical treatments. This was tested previously in other tests, so imposed compressive stresses might have induced some damage.

The fiber samples were evaluated using Spinlab High Volume Instrumentation (HVI) at the LSU Cotton Fiber Testing Laboratory. It is one of the five designated laboratories that cooperate in establishing standardization of instrumental cottons calibration for the cotton industry. HVI (User Model 900 SA) is a set of instruments that connected with the computer, so the properties of fibers, such as micronaire, fiber length, uniformity, index, strength, elongation, color grade, leaf grade, and trash content, can be tested and analyzed. The HVI system meets the strict performance standards established by USDA. It is also in complete accordance with the ASTM standard test method. For natural fibers the system measures fiber length, length uniformity, strength, elongation, micronaire, color, and trash. Test results are automatically calculated relayed to a printer. The optional temperature and relative humidity monitor checks the stability of the testing environment. After automatic brushing of the specimen, a mechanical finger

moves the Fibrocomb into position for testing.

The fineness test began with weighing a fiber sample on the balance. Then the weighed sample was inserted into the micronaire chamber. When the chamber door opened and the sample was ejected, the fineness test was completed. The specimen was optically scanned to determine length. Jaws clamped the specimen and retracted until the fibers were broken. The microprocessor calculated length, uniformity, strength and elongation. Strength was obtained by measuring the force required to break a sample of known mass. Elongation, the length to which the fibers extend before breaking, is also calculated.

Figure 3-1 shows the HVI system. The kenaf fibers with or without chemical treatment were tested. Length in HVI testing was the mean length or the upper half mean length. The strength here was the relationship of the breaking force to the mass of fiber broken, corrected for micronaire and modified by the calibration constants. The units matched the standard values entered for calibration cottons, typically grams per tex (g/tex). The elongation refers to the distance to the maximum of the stress-strain curve, less the distance attributed to crimp, multiplied by 100, and divided by the break gage (1/8 inch).

3.6.2 Yarn Characterization

Kenaf blended yarns and pure cotton yarns were analyzed to compare the effect of spinning methods and kenaf blend ratio to the yarns. In order to observe the structure of different yarns, the yarns were scanned by SEM. The SEM images of the experimental yarns were made in both cross-section and longitude direction. Yarn tensile and elongation were tested by a Uster Tensorapid ^[72].



(a) Overall view of HVI System



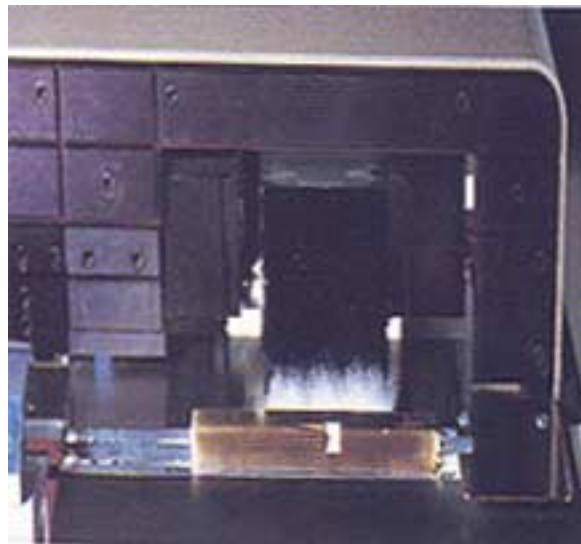
(b) Fibrosampler



(c) Fobrocomb



(d) Color, Trash, Fineness Testing



(e) Length, Length uniformity, Strength and Elongation Testing

Figure 3-1 Spinlab High Volume Instrument System ^[72]

3.6.3 Fabric Characterization

The Kawabata Evaluation System for Fabrics (KES-FB) was used to test tensile and shearing bending, compression, and surface friction and roughness, of the cotton and kenaf blended fabrics. Data was computed and recorded using a computerized data acquisition system. Pictures of Kawabata instruments are showed in figure 3-2.

In the Tensile and shear tester, the sample was clamped between two chucks and stretched. The tensile test was obtained by applying a tensile strain to a sample held by two chucks, by moving the back chuck away from the front chuck. The tensile strain was detected by a potentiometer that senses the movement of the back chuck. The output voltage of the potentiometer was proportional to the strain. When conducting the shear test, the sample was given a constant tensile force and then it is submitted to a shear deformation to a preset shear angle ^[73]. Usually, the sample size should be 20 cm square. Because of the shortage of kenaf blended fabrics, testing samples were cut to 10 cm square, and were tested with two replicates for each fabric sample. Both warp and weft directions were tested. So the typical settings of the instruments were not appropriate and needed to be changed. When testing the tensile property, the distance between the chucks was changed to 2.5 cm instead of 5 cm. And because of the high elasticity of the knitted fabric, the sensitivity of X on the recorder was changed to 0.5, and the standard was 0.1. So the X value needed to be timed 5 to get the true value. The sensitivity of Y was changed into 0.1 instead of 0.2. The shear parameters needed to be hand calculated on the shear curve recorded by the X-Y recorder. The calculation is showed in figure 3-3.

The bending property is one of the components of a hand evaluation system. The

bending tester makes the whole sample bent accurately in a constant curvature, and the curvature was changed continuously. The minute bending momentum if the sample can be detected and the relationship between the bending momentum and the curvature can be measured accurately and quickly. The detection of the bending momentum by the instrument was 0.002gf.cm at full scale ^[74]. In the bending testing, because of the sample size was half of the standard size, the data B—Bending rigidity per unit width (mean of slopes), 2HB--the width of the mean bending hysteresis calculated by the software should be divided by 2 to get the real value. In the surface testing, the samples need to be connected with a 10 cm² cotton fabric each in order to be mounted on the instrument. The cotton parts and the joints were monitored carefully to be sure that they were not included in the testing area on the Kawabata surface tester. For the compression testing, a constant rate of compressional deformation up to the upper-limit force and its recovery process is applied to the sample. The accuracy the compressional testing could be done with 1μm accuracy. The sample was put on the bottom plate after setting the upper-limit force. When the driving motor switch is turned on, a plunger starts to descend and compress the sample at a constant rate ^[75]. The sample size did not affect the compression testing data.

3.6.4 Statistical Analysis

Statistic analysis was done using SAS. Multiple Analysis of Variance (MANOVA) was used to determine if fiber properties differ significantly in terms of retting method, blend percentage, and yarn spinning method. Interactions between the above three factors were determined.



(a) Tensile & Shear Tester



(b) X-Y Recorder



(c) Surface Tester



(d) Compression Tester



(e) Bending Tester

Figure 3-2 Instruments of Kawabata's Evaluation System

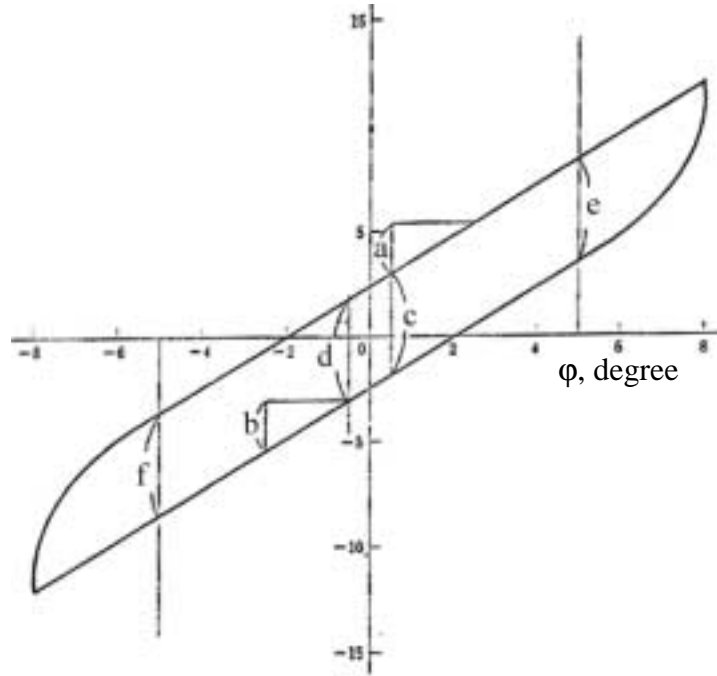


Figure 3-3 Shear: Hand Calculation ^[73]

G: Shear stiffness

$$\frac{a+b}{2 \times 2^\circ} \times 2 \text{ gf/cm}$$

2 HG: Hysteresis of shear force at 0.5° of shear angle

$$\frac{c+d}{2} \times 2 \text{ gf/cm}$$

2HG5: Hysteresis of shear force at 5° of shear angle

$$\frac{e+f}{2} \times 2 \text{ gf/cm}$$

Chapter 4 Results and Discussion

4.1 Kenaf Fiber Testing

4.1.1 Photomicrograph Comparison

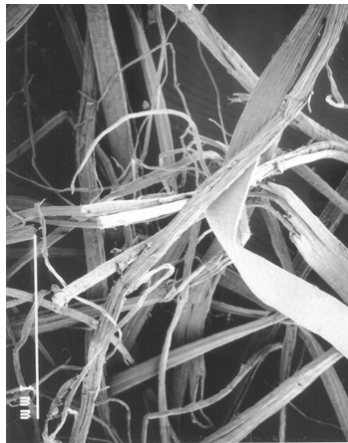
By visual inspection of the kenaf fibers after three different chemical treatments, Kenaf after Treatment 3 was the softest, but the fibers were the shortest. The kenaf fiber treated by Treatment 1 was the coarsest one, as shown in Figure 4-1. Higher concentration of NaOH also made the fibers color darker. Photomicrographs were taken at low and high magnification (50× to 2000×). From the pictures, we can see some difference among the treatments. Kenaf 1 showed the biggest fiber bundles, few individual fibers were found in the picture. The bundles looked very coarse and warped with large amount of lignin. We can see a large fiber bundle of about 1mm diameter. Kenaf 2 reduced the fiber bundle quite obviously, and some single fibers or very small bundles can be found easily. The bundles became much smoother on the surface; the biggest bundles showed in the pictures was about 0.2 mm in diameter, which was one fifth of the ones resulted from treatment 1.

From the 2000× photo, we could see that the lignin began to dissolve, the remained lignin showed a relatively smooth appearance. In the pictures of Kenaf 3, the bundles were finer, some were very well separated. Most of the lignin was removed. We could see the clean and pure kenaf fibers in the picture of high magnification, their average diameter was about 10 μm, this result also corresponded with the data from the literature. In the pictures of all three kenaf samples, the different sizes of fiber bundles were found. In many cases, the fibers were separated at one area but bound together at another, especially in kenaf 3. Kenaf 3 also showed many broken in longitude direction. All the

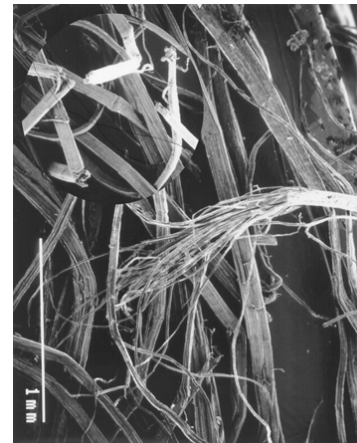
pictures show the fibers tangled with each other. This may increase the amount of fiber broken during the carding process. Figure 4-1 shows photographs of single kenaf fibers.



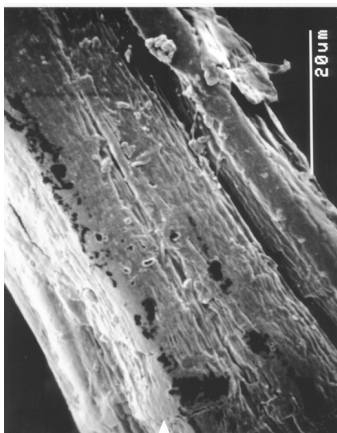
(a) kenaf1--50×



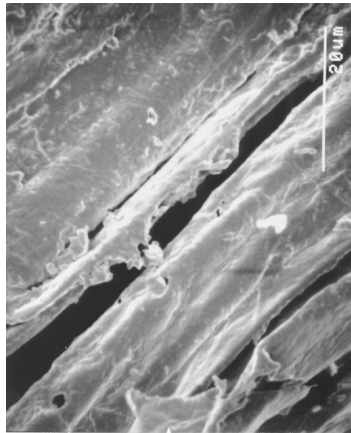
(b) kenaf2--50×



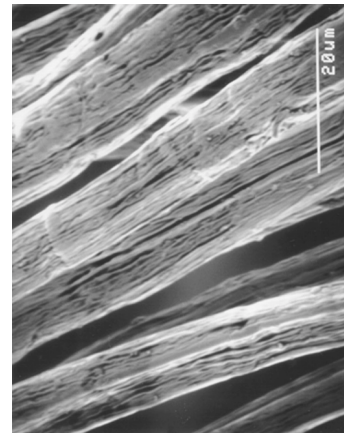
(c) kenaf3--50×



(d) kenaf1--2000×



(e) kenaf 2--2000×



(f) kenaf 3--2000×

Figure 4-1. SEM image of kenaf Fiber with Three Treatments

4.1.2 Physical Properties of the Fibers

Table 2 shows the fiber properties tested by HVI. Data of raw kenaf are also included in the table for comparison.

Table 2. Physical Properties of Kenaf Fibers with Different Treatment

Treatment	Fineness		Length(inch)		Strength (g/tex)		Elongation (%)	
	Micronaire	S.D.	Avg	S.D.	Avg	S. D.	Avg	S.D.
Untreated	9.74	0.113	0.711	0.122	26.97	4.5	1.4	1.1
Treat 1	9.68	0.057	0.735	0.072	17.30	2.9	1.7	0.5
Treat 2	9.52	0.120	0.739	0.073	15.90	3.1	1.8	1.2
Treat 3	9.53	0.198	0.716	0.071	10.45	4.6	2.1	1.7

The fineness testing is the first step when characterizing fibers by the HVI instruments. But according to the HVI Uster's instructions, the highest micronaire the HVI can continue the testing is 8.0, our kenaf fibers are obviously coarser than 8.0. So the tested results of the HVI values for the kenaf can only be used as a reference to compare the effectiveness of treatments. They cannot really reflect the exact fiber fineness. This is also the reason why we got another set of data when the same lots of fiber tested by same type of HVI at USDA Southern Regional Research Center (SRRC) again. In the later testing, the average micronaire and standard deviation of the three treated fibers were 10.59, 10.26, 10.27 and 0.17, 0.36, 0.41 respectively. This was 7% higher than the previous testing, but both testing showed the same trend. The HVI instruments at USDA SRRC did not continue the other testing. According to the data, the fineness of the fibers was increased after treating. And when we increased both boiling time and concentration of sodium hydroxide, the fibers became finer. There was no significant difference between the fiber treated by higher concentration of NaOH or longer extraction time.

The strength of the fibers decreased significantly after treating. Especially when the concentration of NaOH was increased. The strength of fibers after treatment with highly concentrated sodium hydroxide decreased 61% of the original fiber strength. While the fiber treated in low concentration but longer time, the fiber strength lost 41%. Change of the fiber elongation showed an opposite trend. The elongation increased as boiling time or the concentration of NaOH was increased. The elongation values improved 28% and 50% after the treatment 2 and 3 respectively. This is probably because lignin is the main binding material between the kenaf fibers and it is also the main component to keep the rigidity of the kenaf fiber bundle and to stand most of the breaking load during the strength testing. When it partially dissolved in NaOH, the fibers were much easier to separate from each other and more flexible.

The high standard deviation meant that the bundle size reduced by chemical treatment were not evenly. We just hand stirred from time to time during the extraction. Treatment effectiveness was improved by introducing the mechanical agitation. So more even and better quality fibers could be obtained. The strength of mechanical agitation was suggested to be at low level in order to keep the weak fibers from breaking. Since the agitating was not strong during boiling, fiber breaks might also take place after many times of washing.

The length of the fibers did not show a satisfied trend. The untreated fibers were stiffer and straighter so the shorter ones were easier to be picked up by the clamp (fibrosampler). But the treated fibers were softer and somewhat coil, the shorter fibers were not that easy to be included into the sample. This might explain that although the fibers broke a lot during the process, tested results still showed a longer average length

compared to the untreated fibers.

4.2 Kenaf Yarn Spinning

4.2.1 Blending Ratio

To determine the blending ratio, many factors have to be considered. Such as strength, absorbent, resistant to abrasion, color, hand and so on. To obtain the minimum blended fiber length irregularity is one of the most important facts. It is very important to make quality better yarns. The following formulae ^[76] are useful in this research.

- Blended Fiber Average Length

$$L = \sum k_i l_i$$

where k_i is weight rate of each mixed fiber and l_i is average length of each mixed fiber.

- Blended Fiber Length Irregularity (CV)

$$C_L^2 = \sum k_i \left[\left(C_i \frac{l_i}{L} \right)^2 + \left(\frac{l_i}{L} - 1 \right)^2 \right]$$

where C_i is length irregularity of each mixed fiber.

- Optimal Blending Ratio

Considering the blending of the two component fibers, we assume that

$$\alpha = \frac{C_1}{C_2} \quad \beta = \frac{l_2}{l_1}$$

$$k_1 + k_2 = 1$$

where footnotes 1 and 2 indicate the two component fibers respectively.

If we want to obtain a minimum blended fiber length irregularity, the following equivalents must be met:

$$k_2 = \frac{(\beta - 1)^2 - 2(\beta - 1)C_1^2 - (1 - \alpha^2 \beta^2)C_1^2}{(\beta - 1)^3 + 2(\beta - 1)^2 - (\beta - 1)(1 - \alpha^2 \beta^2)C_1^2};$$

Thus, we can determine the optimal blending ratio k_1 and k_2 that may lead to a minimum blended fiber length irregularity ^[76].

In this research, kenaf was blended with cotton. The mean length of cotton was $l_1=1.25$ inch, $C_1=2\%$. The mean length of kenaf fiber after treatment 2 was $l_2=0.739$ inch, with $C_2=7.3\%$. According to the formulae, $k_2 = 63.7\%$. But during the carding process, it was very difficult to get a nice web when kenaf exceeding 60%. So length irregularation was not the only reason we should consider here.

4.2.2 Carding Loss

To illustrate, the yarns were marked with three parts in this paper. The first part (1,2, and 3) indicates the treatment methods; the second part (10, 25, and 50) indicates the kenaf ratio when originally blended with cotton; the third part (O and R) indicates the yarn spinning methods. O represents the Open end Rotor spinning, and R represents the Ring spinning. The control cotton yarns are just marked as A-O (Rotor spun Acala cotton) and A-R (Ring spun). For example, the yarn 2-25-O is the Open end Rotor spun yarn with 25% kenaf and 75% cotton, and the kenaf after treatment 2.

The kenaf and cotton were carded separately first to untangle, parallel, and clean the fibers. Then, they were fed to the carding machine by accurate weight ratios to blend together. It was not too difficult to blend kenaf fibers with cotton fiber during carding. But there was a significant fiber loss during the carding process. When increasing the blending ratio of kenaf, the fiber losses also increased. An effective way to determining the fiber losses of kenaf and cotton separately had not yet been discovered. We could only get the total loss. This also affected the final kenaf ratio in the blended yarns and

fabrics. Fiber losses at the card for the cotton yarn was about 2%, while for the kenaf-blended yarn, the losses went up to 9.7%. Figure 4-1 shows the fiber loss by treatment and blend level.

The average losses for the treatment 1, 2, and 3 were 4.96, 4.51, and 4.20 respectively. It shows a decline trend. A main reason to cause fiber loss was the non-uniformity of the fibers. This also indicates that the treatment 3 produced the finest and softest fiber. The average fiber loss of 10% kenaf blended yarn was 2.01%, less than the pure cotton (2.20%). It also shows that the fiber losses of blended fibers were less than the sum of the fiber losses when carding the pure kenaf or cotton fiber separately. An illustration for this could be the formation of stickiness between the kenaf fiber and cotton fiber after blending.

4.2.3 Kenaf Yarn Spinnability

Treatment 3 was the most difficult one to spin. The fibers were too short and weak to process. Visually, the blended yarns were much coarser than the cotton yarns. The kenaf was not blended very evenly, especially in the low blending ratio. The yarns containing the Kenaf 3 fibers had less kenaf on the surface of the yarns. The high loss in spinning was because of the extremely short fiber length. With lower kenaf blending ratio, yarn spinning was much easier. Open-end Rotor spun yarns containing more kenaf required high levels of twist. In general, the Open-end yarns appeared more uniform than the Ring spun yarns. The Ring spun yarns exhibited a hairy appearance due to the protruding of kenaf fibers. This indicated that kenaf fibers needed to be softened further. The kenaf fibers in the Open-end yarns were less evident.

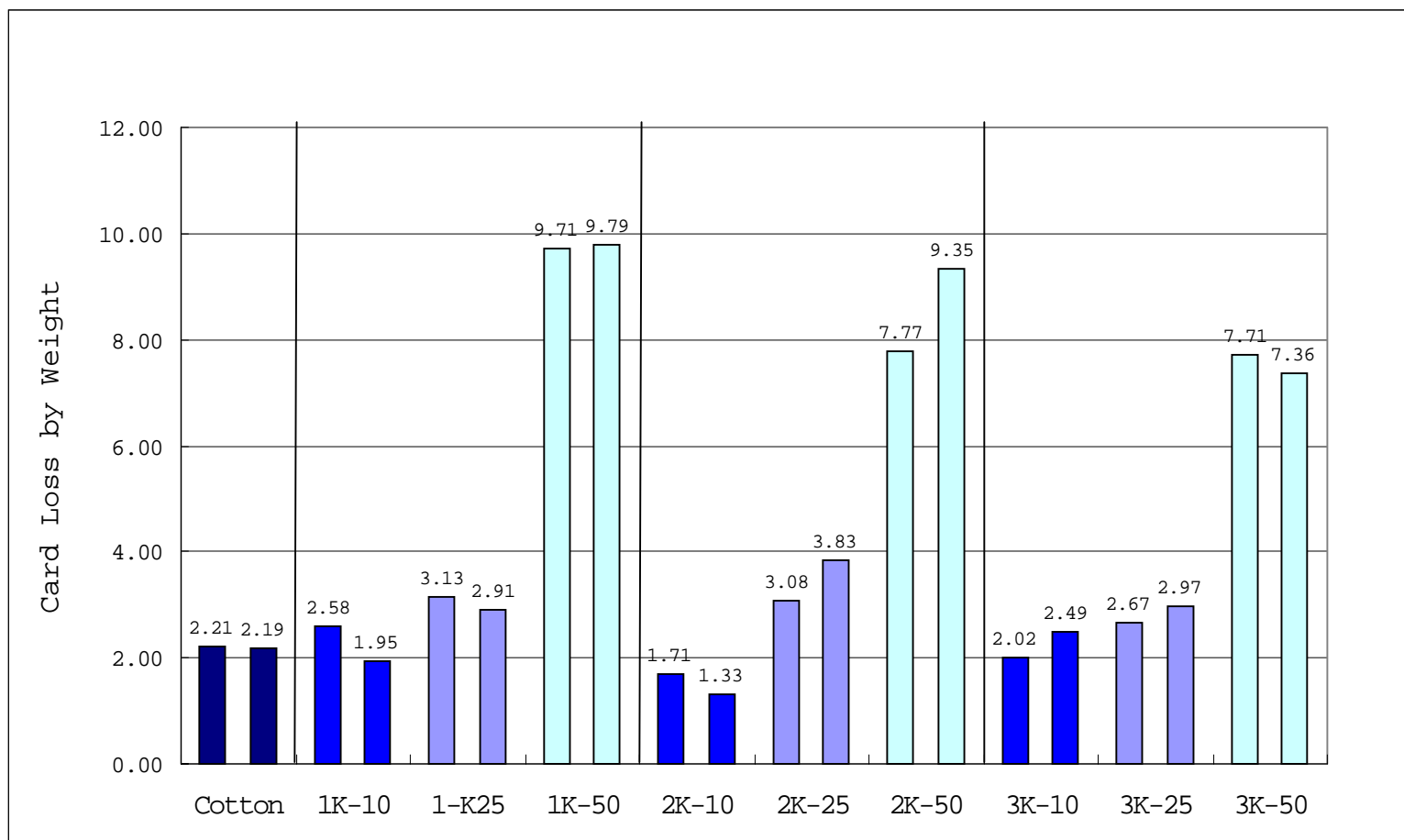
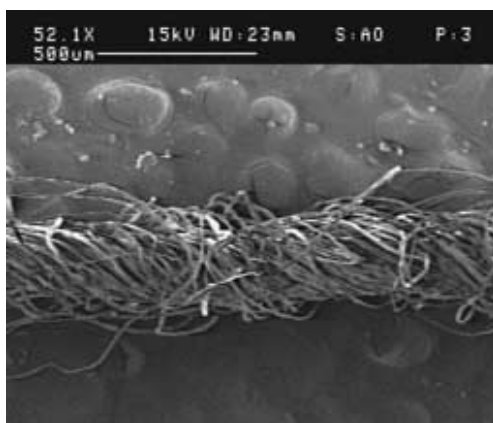


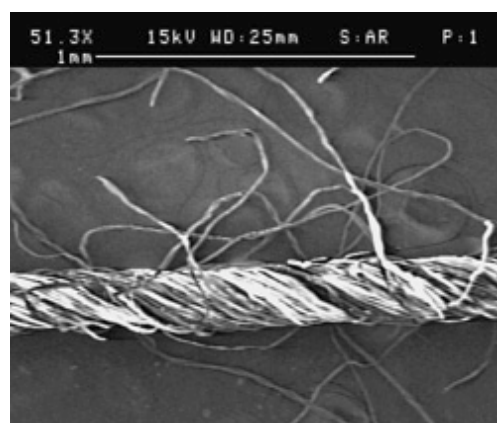
Figure 4-2. Fiber Loss by Treatment and Blend Level

4.2.4 Kenaf Yarn Structure

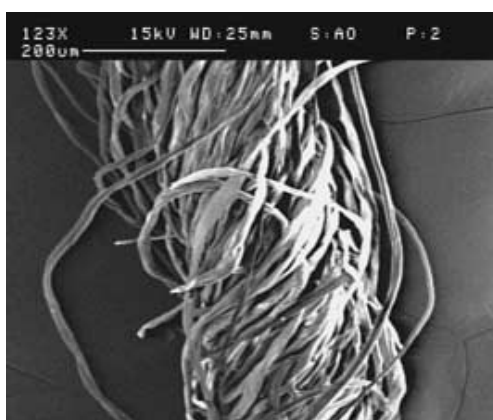
In order to see the affection of spin method on the yarn structure more clearly, SEM pictures were taken with the magnification from 50x to around 120x. We chose only the yarns contain 25% kenaf that treated by the chemical treatment 2 to take pictures, because these yarns were determined to have the best physical performance theoretically. The Rotor spun yarns generally had smoother and tighter structure. In the 100% cotton yarns, there were still some protruding fiber ends. In Rotor spun yarns, the protruding ends hang freely outside the yarns, while in the Ring spun yarns, the ends tangled together, which made the yarns thicker and more uneven. These tangled fibers also made the twist of Ring spun yarns more difficult to measure, because they covered the real trend of the fibers. The diameters of the blended yarns were almost the same as that of the pure cotton yarns, which were about 230 μm . From the pictures of cross-sections, it could be seen that the Ring spun yarns had looser structure, some fibers in the Rotor spun yarns were still clinging together after cutting. The diameter of cut Ring spun yarn was about 20% larger than that of the cut Rotor spun yarn. The diameter of the cut blended yarn intersection did not have significant difference with those of the 100% cotton yarns. This indicated a good blending of the two kinds of fibers. In the pictures of blending yarns, it was not very easy to identify cotton fibers and the fine kenaf fibers but the thick kenaf bundles could be seen very clearly. Many of the thick kenaf bundles clung with cotton only one end and the other ends protruded outside the yarns. Figure 4-2 shows the SEM pictures of the yarns from the two spinning methods.



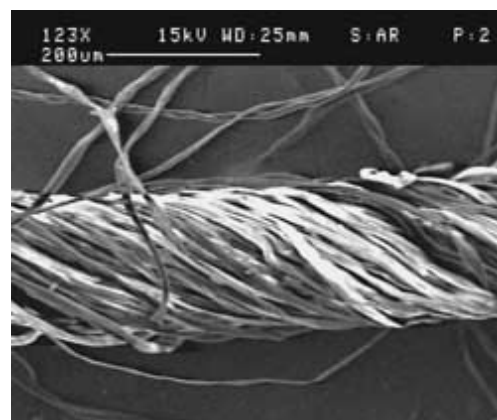
(a) A-R--50x



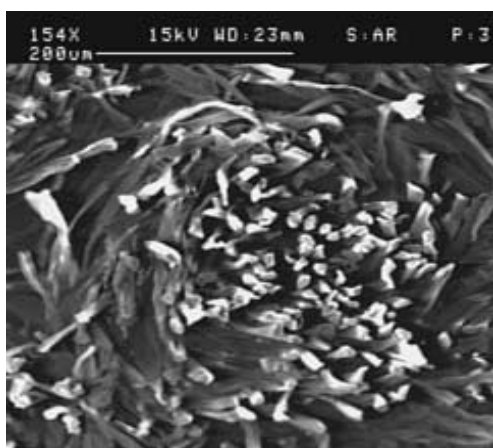
(b) A-O--50x



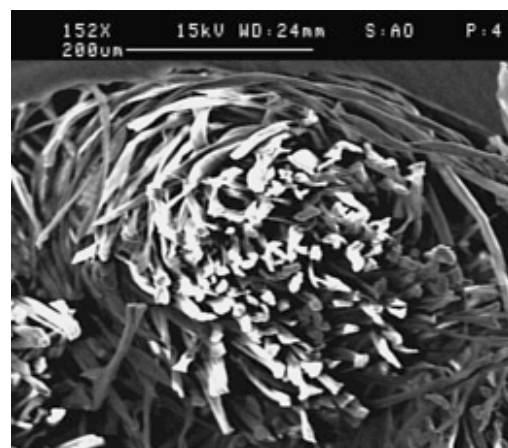
(c) A-R--123x



(d) A-O--123x

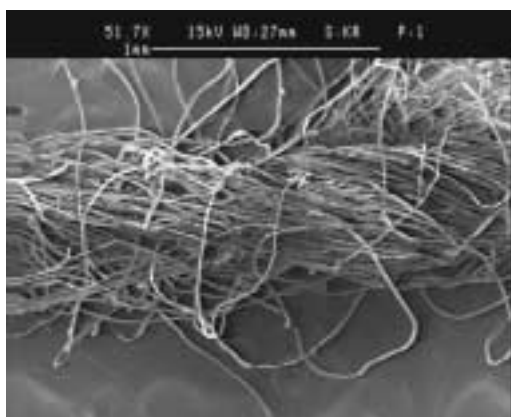


(e) A-R-intersection--154x



(f) A-O-intersection--152x

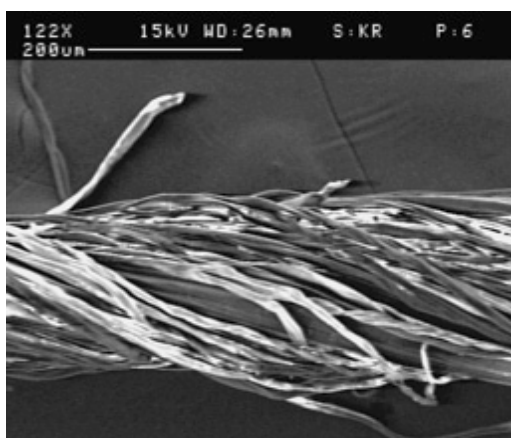
Figure 4-3 SEM pictures of cotton yarns from different spinning methods



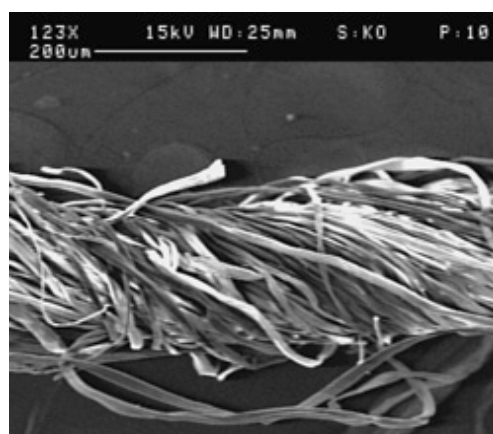
(a) 2-25-R--51x



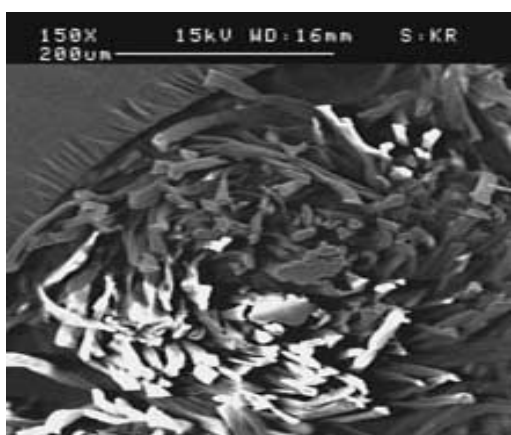
(b) 2-25-O--51x



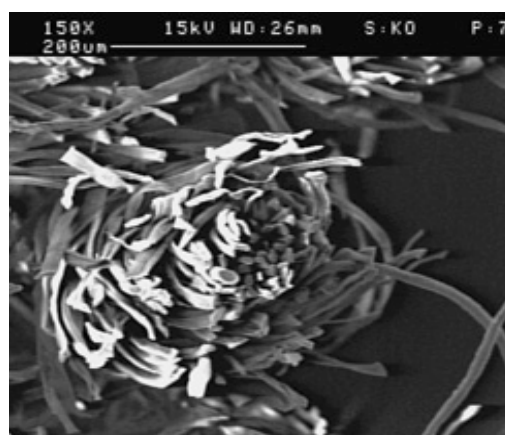
(c) 2-25-R--122x



(d) 2-25-O--123x



(e) 2-25-R-intersection--150x



(f) 2-25-O-intersection--150x

Figure 4-4 SEM pictures of 25% kenaf blended yarns from different spinning methods

4.2.5 Kenaf Yarn Strength

From figure 4-5, we can see the comparison of the yarns' tenacity and elongation. In both spinning methods, pure cotton yarns were the strongest and had the highest elongation. The higher the kenaf blending ratio, the lower the elongation of the yarn was. After blending with kenaf at 50/50 ratio, the tenacity could drop more than 50%. In average, the yarns blended with Kenaf 3 had the lowest tenacity. It was reasonable because Kenaf 3 was the weakest. Kenaf 2 yarns were strongest and longest in terms of tenacity and elongation among the three experimental yarns. This can be explained that though Kenaf 1 was stronger, it was also easier to be broken during the process because they were crispier. Open-end Rotor spun yarns had higher twist in order to keep the ends up but the ring spun yarns tended to be stronger. The average tenacity of the ring spun yarns was about 20% stronger. The high twist of the rotor yarns also made them more stretching. This can also be understood that compared with the pure cotton yarn and ring spun yarn, the elongation of the high-blend-ratio yarns was not reduced as much as that of the Ring spun yarn.

4.3 Fabric Properties

4.3.1 General Description

The kenaf blended yarns were knitted into experimental fabrics. The knitted fabrics were cut into 10×10 cm squares. The fabrics showed very beautiful natural color. When increasing the blend ration of kenaf, the color of fabrics became darker. At the same blending ratio, treatment 1 gave the lightest color, while Treatment 2 looked darkest. But the color difference between Treatment 2 and Treatment 3 was not obvious. By visual inspection, the fabrics knitted from the open-end Rotor yarns were smoother than those knitted from the ring spun yarns. This also caused lots of knitting faults on the fabrics from Ring spun yarns, mainly the missing loops. From the pictures, we can could

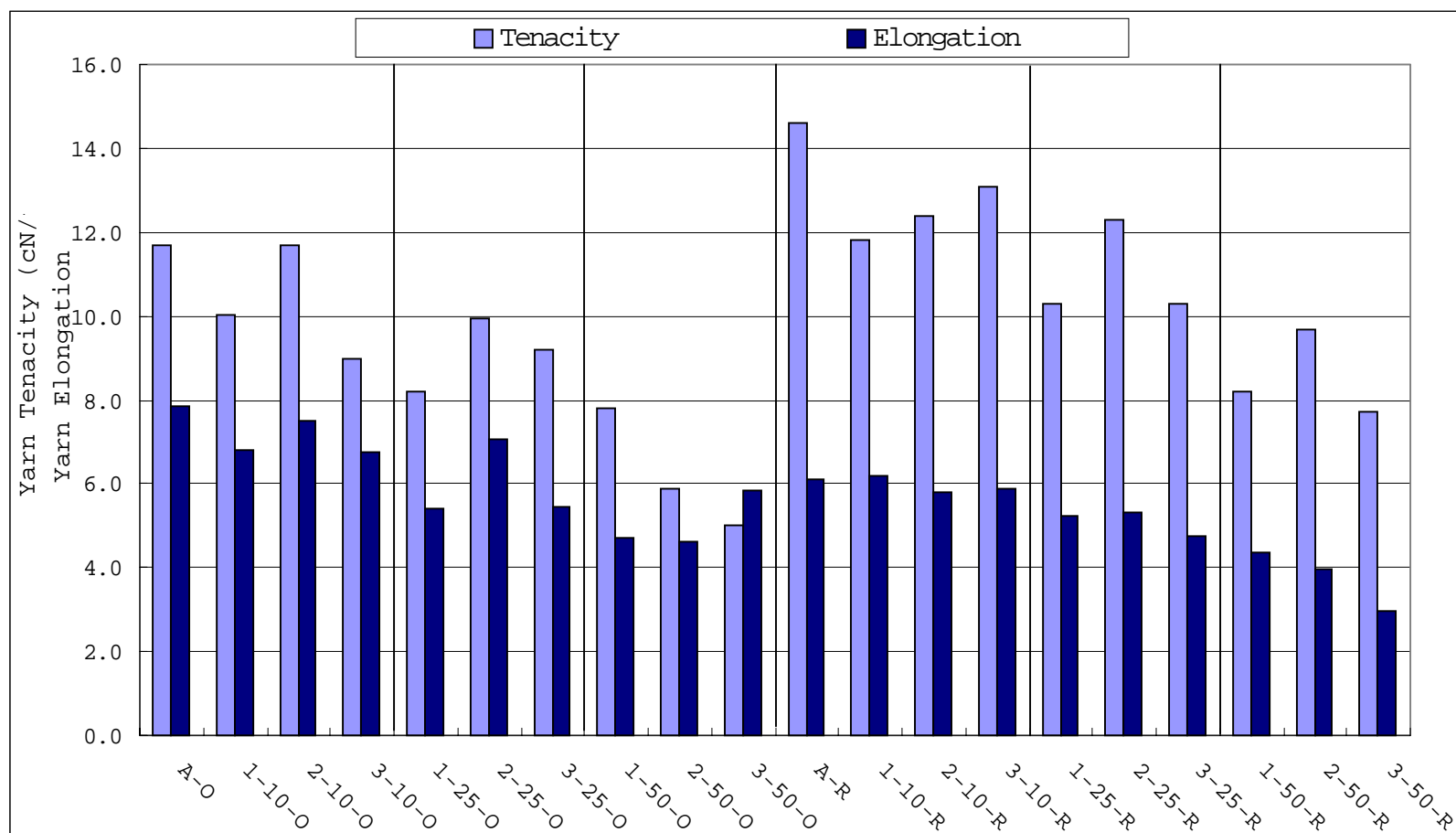


Figure 4-5. Kenaf/Cotton Blend Yarns Strength Properties

observe that in the rotor-spun fabrics, kenaf and cotton were blended very well, but in the ring-spun fabrics, we can separate the kenaf parts and the cotton parts. The quality of yarns also affected the thickness of the fabrics. The average thickness of K-50-O was 2.157 mm, and K-50-R was 1.505 mm. It is because the higher twist of the Rotor yarns that made the fabric more bulky. Because of the unevenness of the ring spun yarns, some parts of the fabric were sheerer than the average thickness, while some parts were thicker. This unevenness also made the fabrics show lighter color in some parts than the others. A skewed grain could be seen on the Ring fabrics.

The higher the blending ratio of kenaf, the more unevenness the fabrics were. There were a lot of little darker dots on the surface of the 10% Ring-spun kenaf fabrics. Cotton parts, kenaf parts, and blended parts were not very difficult to identify visually. But on the fabrics knitted with the 10% Rotor yarns, the situation was much better. This was also resulted from the higher twist of Rotor yarns. The higher the kenaf content, the more different between the fabrics surface appearance was.

In the 50% ring kenaf fabrics, some parts were almost semitransparent. The thickness of these kinds of parts was as much as 2.5 times less than the thickest parts. These fabrics also had a lot of missing loops and the yarns were broken from time to time. But the 50% Rotor kenaf fabrics showed very evenly in both color and thickness. They were more even than the 25% and 10% Rotor kenaf fabrics. The kenaf and cotton seemed to blend very well with each other. With the increasing ratio of kenaf, the color of the fabrics also became darker. The colors of the fabrics from Ring spun yarns were slightly lighter than the other fabrics. This was very obvious on the 50% kenaf fabrics. It might indicate that the Ring spun yarns lost more kenaf fibers during knitting. For fabric

hand, the higher the kenaf content, the stiffer the fabric. The fabric hand was very harsh for the 50% kenaf fabrics. But there was no significant difference between the 10% kenaf fabrics and cotton fabrics. All the blended fabrics, even the 10 percent kenaf fabrics, were too coarse to contact directly to people's skin. Figure 4-6 exhibits how the fabrics look like.

As discussed above, the blending ratios were the ratio of the amount of kenaf and cotton before spinning, the actual kenaf ratio was lower than the designed value. Because the kenaf fiber was stiffer and shorter than cotton fiber, the losses of the two kinds of fiber were not the same during the knitting process. This made the content of kenaf even lower. An effective way to find the exact kenaf content has not been found out yet.

4.3.2 KAWABATA Testing

Both cotton fabrics and cotton/kenaf blended fabrics were tested by the KAWABATA system to determine their tensile, shear, bending, compression and surface properties. Table 3 and Table 4 showed the resulted data. This data was later tested by the MANOVA method to check if there was a significant influence of chemical treatment methods, spinning methods and blending ratio on the fabric properties. At 95% confidential level, i.e. $\alpha=0.05$, this parameter was considered to have significant affection to the corresponding property. As showed in Table 5, spinning method affected all of the parameters except compression energy (WC). Blending ratio has no influence on compression rate (EMC) only. Chemical treatment also affected most of the Kawabata parameters. But in many situations, though spinning method, treatment and blending ratio significantly affected the parameters separately, but when considering the effect of two of them or all of them, the effect seemed to disappear. It could be understood that



(a) A-R



(b) A-O



(c) 2-10-R



(d) 2-10-O

Figure 4-6 Structures of Fabrics Knitted from Ring Spun Yarns and Open-end Rotor Spun Yarn



(e) 2-25-R



(f) 2-25-O



(g) 2-50-R



(h) 2-50-O

Figure 4-6 (continued)

interaction were among these main effects, some main effects worked in an opposite trend.

In the table 3 and table 4, the meanings of the parameters are below:

Bending properties:

B: Bending Rigidity (gf cm/cm)

HB: Hysteresis of bending moment (gf cm/cm)

Tensile properties:

LT: Linearity of tensile curve

WT: Tensile energy (gf cm/cm²)

RT: Tensile Resilience (%)

EMT: Tensile strain (%)

Surface properties:

SMD: Surface roughness

MIU: The mean frictional coefficient

MMD: Fluctuation of the frictional coefficient

Shear properties:

G: Shearing stiffness (gf /cm degree)

2HG: Hysteresis of shear force at 0.5° of shear angle (gf/cm)

2HG5: Hysteresis of shear force at 5° of shear angle (gf/cm)

Compression properties:

WC: Compressional energy (gf cm/cm²)

To: Fabric thickness (mm)

RC: Compressional resilience (%)

EMC: Compression rate (%)

LC: Linearity of compression thickness curve

Table 3 KAWABATA Testing Data for the fabrics from open-end rotor spun yarns

Spun method	Treatment	Blend Ratio	B	2HB	LT	WT	RT	EMT	SMD	MIU	MMD	G	2HG	2HG5	LC	WC	RC	To	EMC
O	0	0	0.0076	0.0116	0.671	3.730	29.25	21.65	9.3579	0.2779	0.0352	0.850	2.580	2.520	0.258	0.227	12.82	0.352	100.00
O	0	0	0.0073	0.0113	0.664	3.760	29.63	21.45	9.2430	0.2590	0.0358	0.850	2.420	2.430	0.365	0.351	16.09	0.384	100.00
O	1	10	0.0185	0.0243	0.769	3.560	35.67	20.28	10.3063	0.2856	0.0576	1.305	4.100	4.020	0.391	0.822	26.51	0.848	94.16
O	1	10	0.0189	0.0268	0.753	3.720	34.95	21.33	10.3439	0.2857	0.0517	1.385	3.670	3.420	0.352	0.872	26.43	1.027	89.73
O	1	25	0.0193	0.0251	0.753	3.225	36.94	18.90	10.4433	0.3452	0.0660	1.410	4.380	4.120	0.399	0.884	30.87	1.776	85.04
O	1	25	0.0198	0.0256	0.773	3.395	35.23	19.25	10.4849	0.3245	0.0636	1.470	4.120	4.420	0.420	0.852	27.21	1.584	78.74
O	1	50	0.1660	0.1716	0.888	2.985	40.03	14.15	11.7854	0.3560	0.0928	2.870	7.420	6.800	0.420	1.308	42.78	2.364	79.07
O	1	50	0.1491	0.1810	0.927	2.855	39.40	14.03	10.6761	0.3559	0.0972	2.885	7.340	7.000	0.436	1.429	48.71	2.501	74.66
O	2	10	0.0147	0.0198	0.753	3.720	31.45	20.45	9.3839	0.2822	0.0554	1.290	3.660	3.950	0.346	0.701	24.55	0.813	84.61
O	2	10	0.0147	0.0203	0.710	3.725	29.53	20.50	9.3976	0.2782	0.0475	1.260	3.310	4.200	0.317	0.703	25.77	0.839	84.60
O	2	25	0.0166	0.0214	0.734	3.475	38.27	16.78	9.6845	0.3058	0.0600	1.295	3.990	4.200	0.357	0.804	25.02	1.084	83.02
O	2	25	0.0179	0.0210	0.733	3.285	35.77	18.03	9.5442	0.3054	0.0586	1.455	4.400	4.050	0.423	0.721	33.27	0.897	76.10
O	2	50	0.1319	0.1556	0.913	3.140	37.61	14.08	11.5348	0.3335	0.0879	2.735	6.540	5.800	0.369	1.191	42.08	1.573	67.16
O	2	50	0.1423	0.1790	0.914	3.250	37.90	12.50	11.0716	0.3408	0.0910	2.650	6.830	8.250	0.341	1.278	32.17	2.500	72.02
O	3	10	0.0163	0.0204	0.691	3.735	30.58	18.40	9.3517	0.2771	0.0508	1.285	3.290	3.220	0.149	0.661	22.58	0.847	93.22
O	3	10	0.0158	0.0220	0.763	3.760	29.95	18.25	9.2234	0.2920	0.0519	1.305	3.620	3.810	0.149	0.569	19.67	0.944	93.47
O	3	25	0.0165	0.0211	0.727	3.710	36.68	17.78	9.5146	0.3134	0.0605	1.415	3.900	3.730	0.304	0.658	31.25	0.848	77.76
O	3	25	0.0142	0.0212	0.741	3.670	33.66	19.70	10.0622	0.3320	0.0632	1.260	3.800	4.300	0.421	0.891	30.96	1.121	75.72
O	3	50	0.1481	0.1699	0.898	3.310	36.28	13.75	9.9927	0.3314	0.0907	2.475	6.750	6.580	0.272	1.143	47.29	2.083	59.27
O	3	50	0.1327	0.1757	0.918	3.030	36.52	13.20	11.9747	0.3726	0.0829	2.385	6.970	6.360	0.306	1.044	40.85	1.920	60.54

Table 4 KAWABATA Testing Data for the fabrics from open-end rotor spun yarns

Spun method	Treatment	Blend Ratio	B	2HB	LT	WT	RT	EMT	SMD	MIU	MMD	G	2HG	2HG5	LC	WC	RC	To	EMC
R	0	0	0.0098	0.0129	0.832	3.875	52.26	18.63	9.0690	0.2822	0.0547	1.135	3.360	3.610	0.300	0.283	5.44	0.398	94.87
R	0	0	0.0102	0.0160	0.797	3.615	44.40	18.15	8.2230	0.2791	0.0478	1.160	3.410	3.420	0.363	0.426	4.84	0.520	90.22
R	1	10	0.0114	0.0177	0.838	3.520	48.01	16.80	9.1942	0.2820	0.0542	1.205	3.540	3.900	0.392	0.639	9.26	0.777	83.92
R	1	10	0.0125	0.0203	0.782	3.605	37.60	16.40	9.1909	0.3225	0.0536	1.345	3.500	3.800	0.366	0.591	8.35	0.704	91.90
R	1	25	0.0149	0.0199	0.761	3.540	34.30	19.13	9.9930	0.3026	0.0840	1.330	3.930	3.850	0.402	0.927	17.70	1.140	80.95
R	1	25	0.0149	0.0194	0.737	3.295	35.39	17.88	9.3342	0.3137	0.0835	1.395	3.790	4.000	0.434	0.786	17.79	0.798	90.74
R	1	50	0.0158	0.0294	0.719	3.280	33.93	18.25	10.6716	0.3543	0.0912	1.500	4.060	4.380	0.463	1.220	22.32	1.438	73.36
R	1	50	0.0192	0.0272	0.760	3.405	32.93	17.93	10.0516	0.3696	0.0887	1.390	4.480	4.200	0.478	1.121	19.34	1.270	73.92
R	2	10	0.0115	0.0169	0.770	3.485	41.18	18.10	9.0981	0.2928	0.0610	1.070	3.070	3.150	0.331	0.421	8.73	0.555	93.26
R	2	10	0.0115	0.0190	0.795	3.290	43.01	16.55	9.8491	0.2991	0.0670	1.125	3.340	3.500	0.324	0.426	6.66	0.545	96.62
R	2	25	0.0133	0.0202	0.712	3.370	33.38	13.33	10.5661	0.2893	0.0582	1.300	4.070	3.970	0.329	0.948	24.49	1.288	89.29
R	2	25	0.0131	0.0209	0.760	3.200	34.69	22.88	9.7794	0.3047	0.0825	1.290	4.660	4.460	0.388	1.046	27.84	1.179	91.50
R	2	50	0.0161	0.0247	0.695	3.290	29.64	18.93	10.0582	0.3314	0.0795	1.475	6.540	4.450	0.406	1.374	29.98	1.653	83.41
R	2	50	0.0160	0.0238	0.721	2.856	36.68	15.85	10.0405	0.3290	0.0713	1.415	5.100	4.550	0.424	1.313	26.79	1.430	86.54
R	3	10	0.0121	0.0144	0.751	3.400	36.29	19.40	9.2672	0.2865	0.0585	1.080	3.430	3.530	0.333	0.720	8.14	0.901	96.10
R	3	10	0.0115	0.0152	0.720	3.512	35.81	17.33	8.7374	0.2784	0.0523	1.185	3.870	3.780	0.333	0.704	8.62	0.884	95.56
R	3	25	0.0126	0.0198	0.704	3.000	30.44	10.23	10.2764	0.2729	0.0687	1.175	4.120	4.170	0.354	0.886	22.19	1.168	85.81
R	3	25	0.0121	0.0206	0.739	3.170	32.54	13.40	9.5039	0.2910	0.0559	1.160	3.910	3.800	0.334	0.854	25.57	0.964	87.82
R	3	50	0.0191	0.0271	0.724	3.000	29.33	16.58	9.8531	0.3171	0.0731	1.390	4.460	4.330	0.362	1.103	24.45	1.539	79.30
R	3	50	0.0157	0.0232	0.709	2.963	25.86	19.75	10.1546	0.3203	0.0840	1.380	4.780	4.680	0.404	1.152	29.82	1.702	80.97

Table 5 MANOVA Testing Data-- Value of $p < 0.05$

Main Effect	Bending		Tensile			
	B	2HB	LT	WT	RT	EMT
Spun	Y(p< 0.0001)	Y(p<0.0001)	Y(p=0.0447)	Y(p=0.0238)	Y(p=0.0233)	Y(p=0.0004)
Treatment	Y(p=0.0121)	N(p=0.0905)	Y(p=0.0135)	N(p=0.8913)	N(p=0.2131)	Y(p=0.0023)
Spun \times Treatment	N(p=0.0572)	N(p=0.3809)	N(p=0.5596)	Y(p=0.0003)	N(p=0.7001)	N(p=0.2557)
Ratio	Y(p<0.0001)	Y(p<0.0001)	Y(p<0.0001)	Y(p<0.0001)	Y(p=0.0042)	N(p=0.3087)
Spun \times Ratio	Y(p<0.0001)	Y(p<0.0001)	Y(p<0.0001)	Y(p=0.0341)	Y(p=0.0003)	Y(p<0.0001)
Treatment \times Ratio	N(p=0.178)	N(p=0.7588)	N(p=0.507)	N(p=0.9016)	N(p=0.3546)	N(p=0.6614)
Spun \times Treatment \times Ratio	N(p=0.1741)	N(p=0.9741)	Y(p=0.6764)	N(p=0.1431)	Y(p=0.0461)	N(p=0.8123)

Main Effect	Shearing Angle			Surface	
	G	2HG	2HG5	MIU	MMD
Spun	Y(p<0.0001)	Y(p=0.0008)	Y(p=0.0047)	Y(p=0.045)	Y(p=0.0167)
Treatment	Y(p<0.0001)	N(p=0.2527)	N(p=0.5852)	Y(p=0.0023)	Y(p=0.013)
Spun \times Treatment	N(p=0.3632)	Y(p=0.0036)	N(p=0.4724)	Y(p=0.0294)	N(p=0.449)
Ratio	Y(p<0.0001)	Y(p<0.0001)	Y(p<0.0001)	Y(p<0.0001)	Y(p<0.0001)
Spun \times Ratio	Y(p<0.0001)	Y(p<0.0001)	Y(p<0.0001)	Y(p=0.0063)	Y(p=0.0013)
Treatment & Ratio	Y(p=0.0312)	N(p=0.1138)	N(p=0.9859)	N(p=0.5836)	N(p=0.1213)
Spun \times Treatment \times Ratio	Y(p=0.0022)	Y(p=0.0173)	N(p=0.612)	N(p=0.703)	N(p=0.1372)

Main Effect	Surface				
	LC	WC	RC	To	EMC
Spun	Y(p=0.007)	N(p=0.9915)	Y(p<0.0001)	Y(p=0.0015)	Y(p=0.0004)
Treatment	Y(p<0.0001)	Y(p=0.0175)	N(p=0.6147)	N(p=0.1359)	N(p=0.337)
Spun \times Treatment	Y(p=0.0222)	Y(p=0.0021)	Y(p=0.009)	Y(p=0.0028)	Y(p<0.0001)
Ratio	Y(p<0.0001)	Y(p<0.0001)	Y(p<0.0001)	Y(p<0.0001)	Y(p<0.0001)
Spun \times Ratio	Y(p=0.0149)	Y(p=0.0013)	Y(p=0.0011)	Y(p=0.0038)	Y(p=0.0149)
Treatment \times Ratio	N(p=0.2168)	Y(p=0.0063)	N(p=0.1234)	N(p=0.3887)	Y(p=0.0081)
Spun \times Treatment \times Ratio	Y(p=0.0459)	Y(p=0.0099)	N(p=0.1172)	N(p=0.127)	Y(p=0.0377)

Comparing the average value of each group, some trends of the fabric properties could be found. Bending and shearing angle were the two properties that reflect the softness of the fabrics. Roughness and friction reflected the fabric surface smoothness. The value of the LT were timed 10, in order to put the three properties into one chart. Otherwise, the column represented them would be too small to compare. As shows in Figure 4-7 to figure 4-11, when increasing the kenaf in the fabric, both bending rigidity and shear stiffness increased. The bending rigidity of fabrics with 50% kenaf was about 4 times greater than that of the fabrics with 10% kenaf. Surface properties showed the same trend, the higher the kenaf contented, the rougher the fabrics were.

Chemical treatment did not have the effect on the fabric as much as the blending ratio, the biggest difference was within 10%. From Figures 4-12 to 4-16 we could see that fabrics from Treatment 1 was the stiffest; Treatment 2 and 3 were almost the same in many parameters. In B and BH, Treatment 3 was even a little bigger than Treatment 2. This was probably because the chemical treatment didn't change the fiber properties that much. But on the other hand, the kenaf content in the fabric could affect fabric properties.

Spinning method was another important fact that affected the softness and smoothness of the fabrics. Figures 4-17 to 4-21 compared the properties of the fabrics knitted from open-end rotor spun yarns and ring spun yarns. Because of the higher twist level of Open-end rotor spun yarns, the fabrics knitted from them also had higher rigidity. The B and HB of the fabrics from Rotor spun yarns were almost 4 times bigger than that of the fabrics from Ring spun yarn. The shearing parameters showed the same trend but the differences between the two kinds of fabrics were much less. And these higher twist

level also made the fabric from Rotor spun yarns have smoother surface, because the higher twist kept the fiber ends better.

With the increasing blending ratio the fabrics became weaker, had lower resilience, and needed higher compression energy but the compression resilience got higher. The compression properties may also be affected because of the different thickness of the fabrics with different kenaf. But in general, high kenaf content made the fabrics stiffer.

Blending with large amount of cotton also weakened the effect of chemical treatment to the kenaf fibers. The strength of the fabrics from different treatments did not have too much difference. But Treatment 3 made the fabrics more stretch, higher compression resilience, and the lowest compression energy. Spinning methods data did not show a quite ideal pattern. We expected that fabrics from Open-end Rotor spun yarns were stronger, higher compression energy, and lower compression resilience. But there were not much difference in strength and compression energy according to the data.

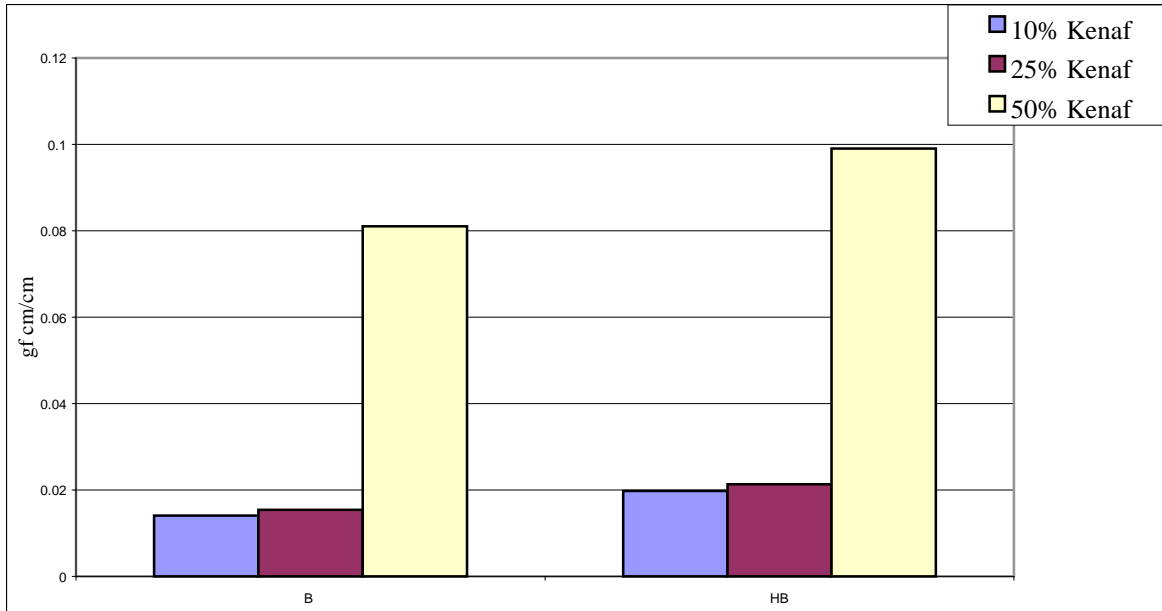


Figure 4-7 Bending Properties of Kenaf/Cotton Fabrics with Different Blending Ratio

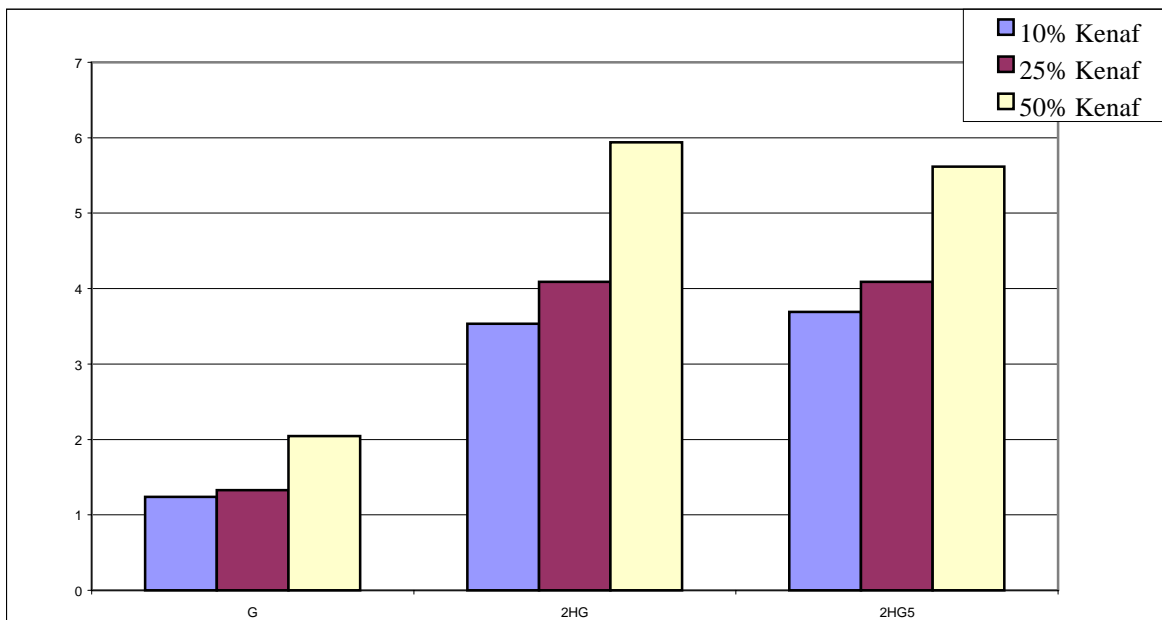


Figure 4-8 Shear Properties of Kenaf/Cotton Fabrics with Different Blending Ratio

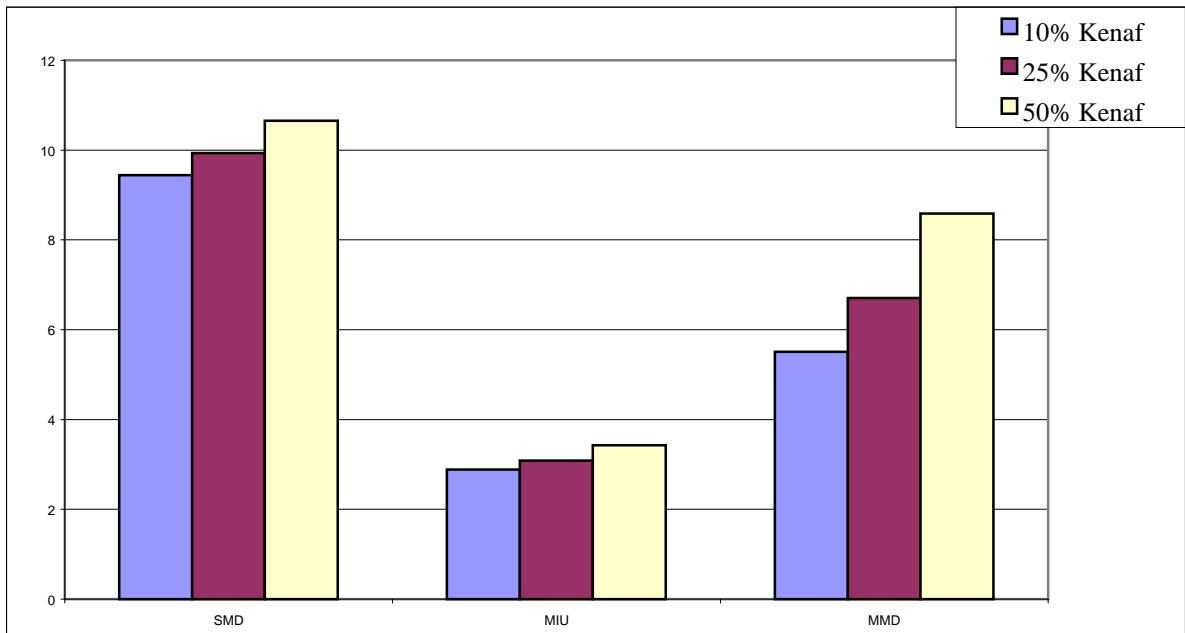


Figure 4-9 Surface Properties of Kenaf/Cotton Fabrics with Different Blending Ratio

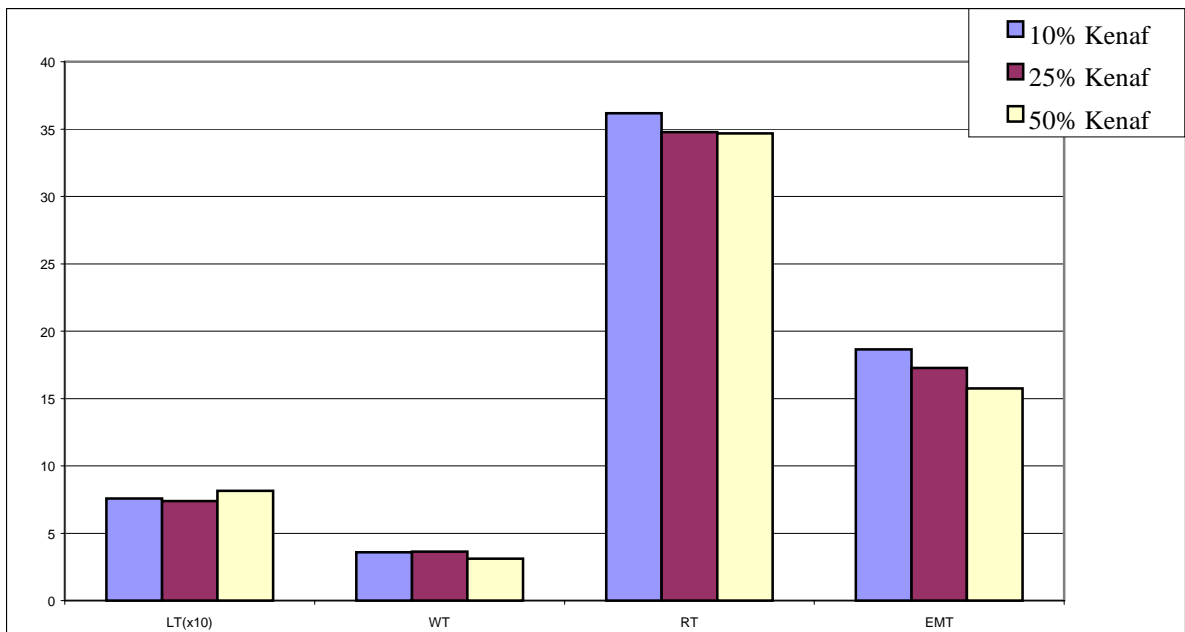


Figure 4-10 Tensile Properties of Kenaf/Cotton Fabrics with Different Blending Ratio

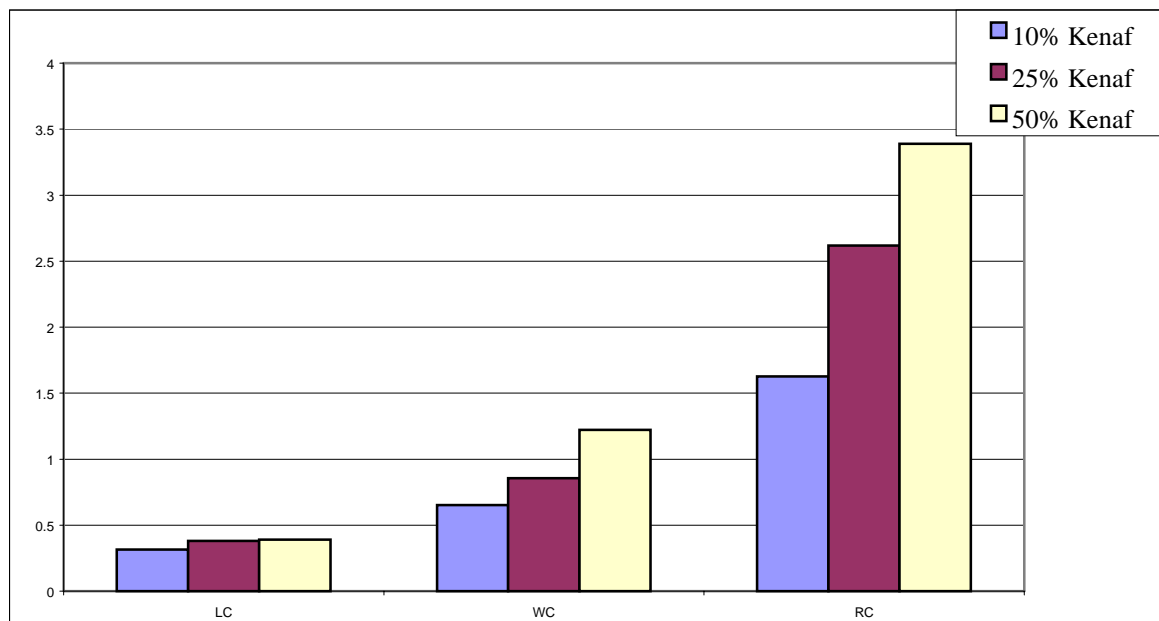


Figure 4-11 Compression Properties of Kenaf/Cotton Fabrics with Different Blending Ratio

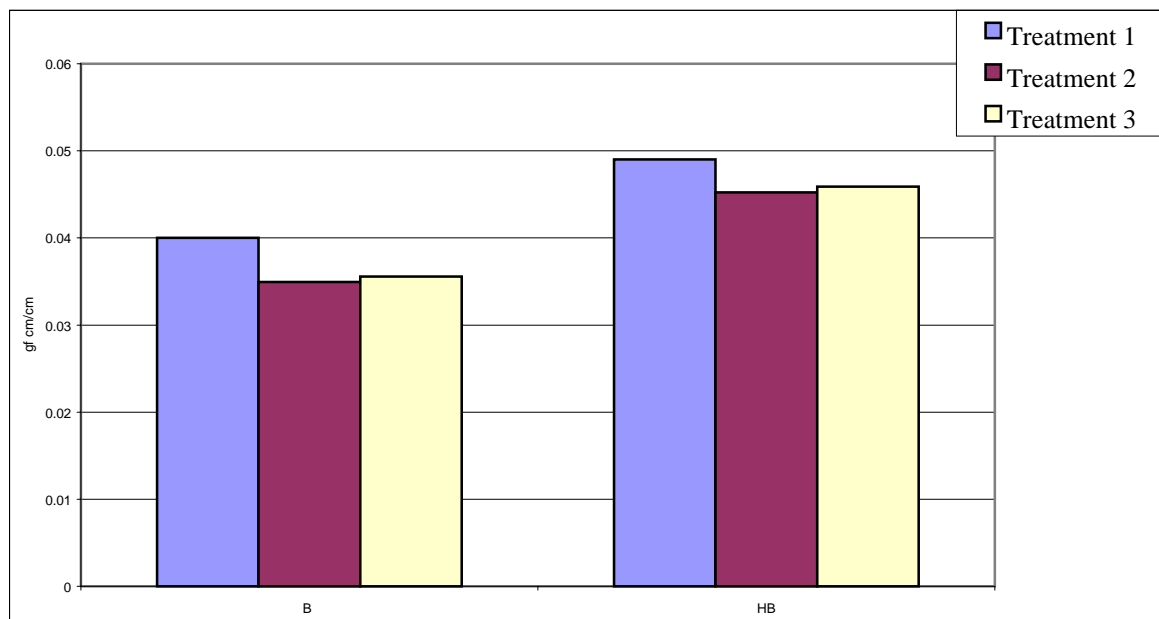


Figure 4-12 Bending Properties of Kenaf/Cotton Fabrics from Kenaf with Different Chemical Treatment

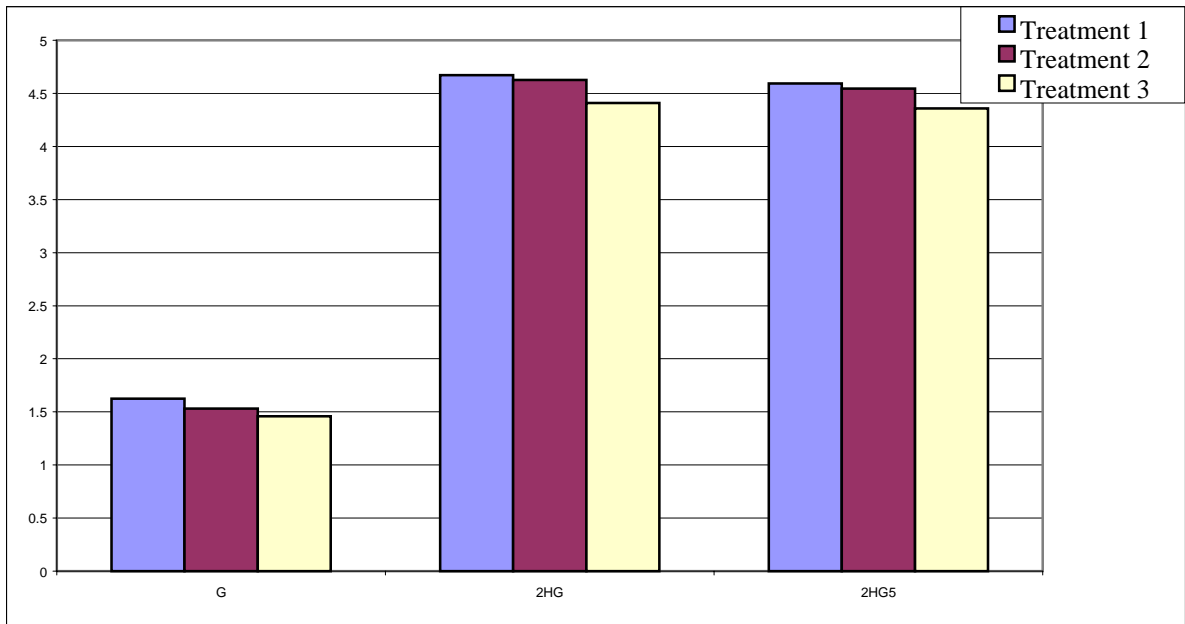


Figure 4-13 Shear Properties of Kenaf/Cotton Fabrics from Kenaf with Different Chemical Treatment

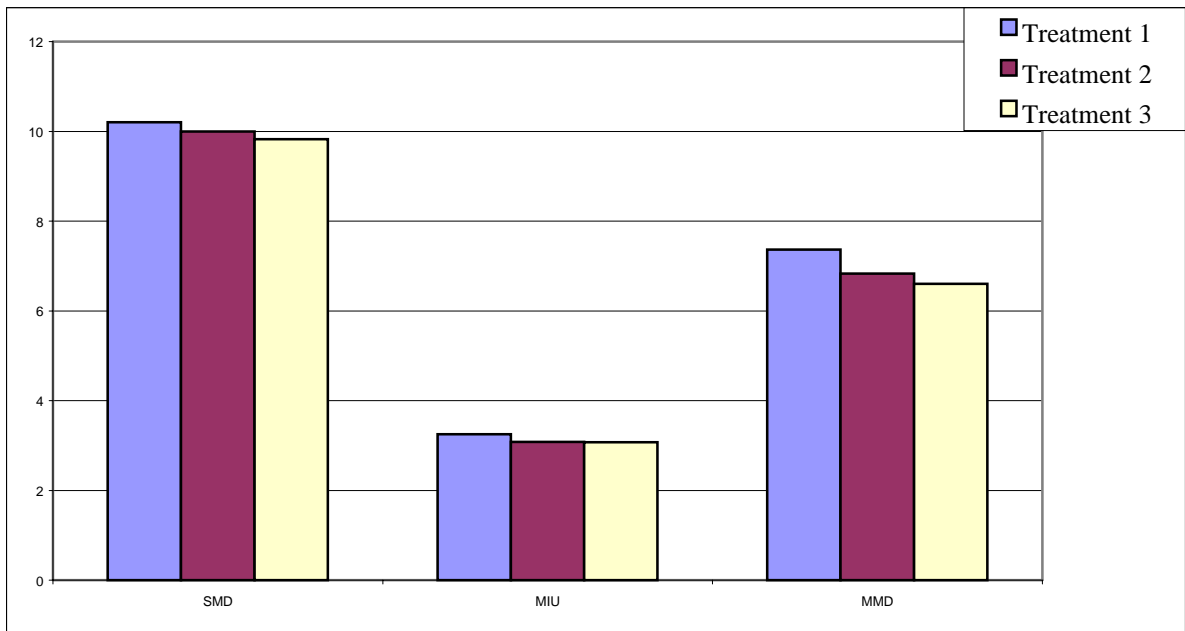


Figure 4-14 Surface Properties of Kenaf/Cotton Fabrics from Kenaf with Different Chemical Treatment

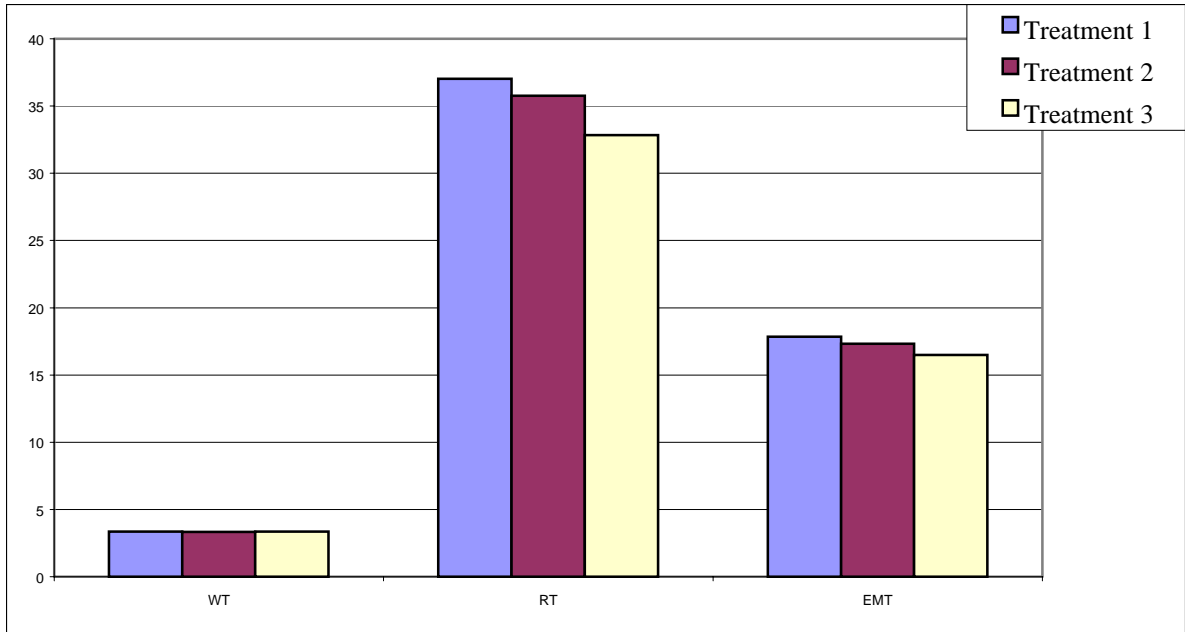


Figure 4-15 Tensile Properties of Kenaf/Cotton Fabrics from Kenaf with Different Chemical Treatment

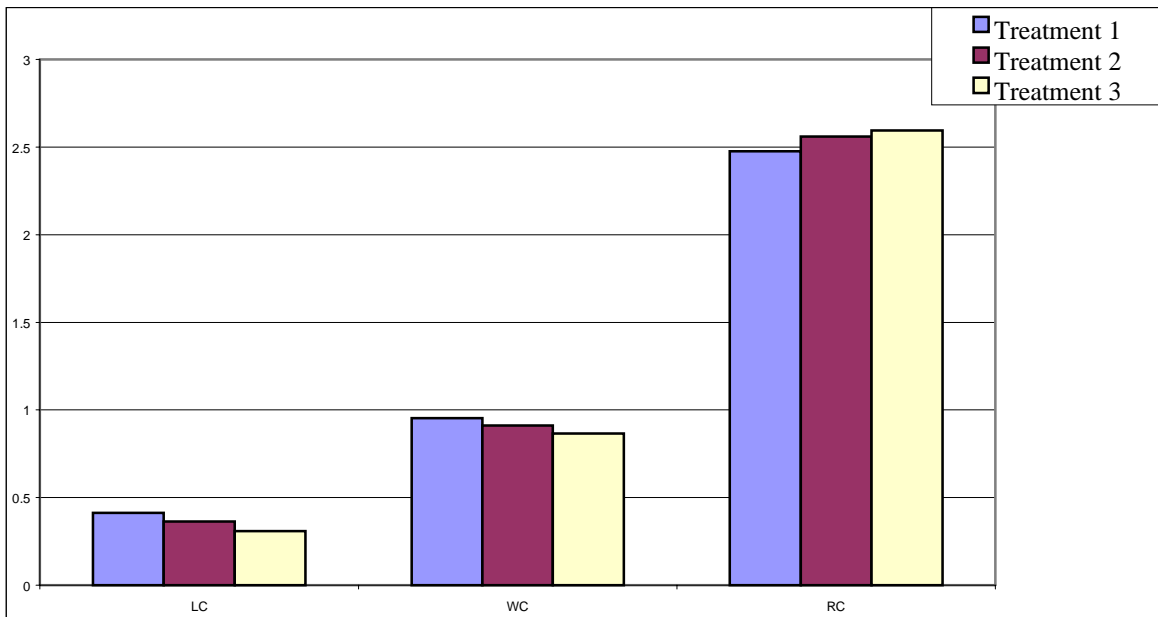


Figure 4-16 Compression Properties of Kenaf/Cotton Fabrics from Kenaf with Different Chemical Treatment

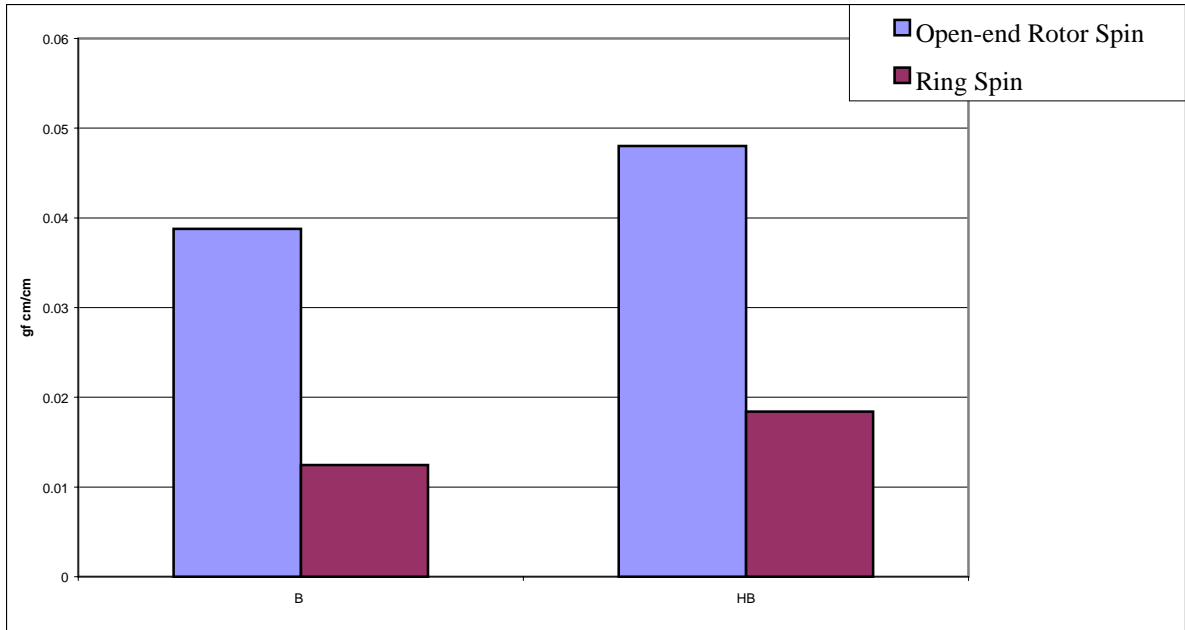


Figure 4-17 Bending Properties of Kenaf/Cotton Fabrics from Yarns with Different Spun Method

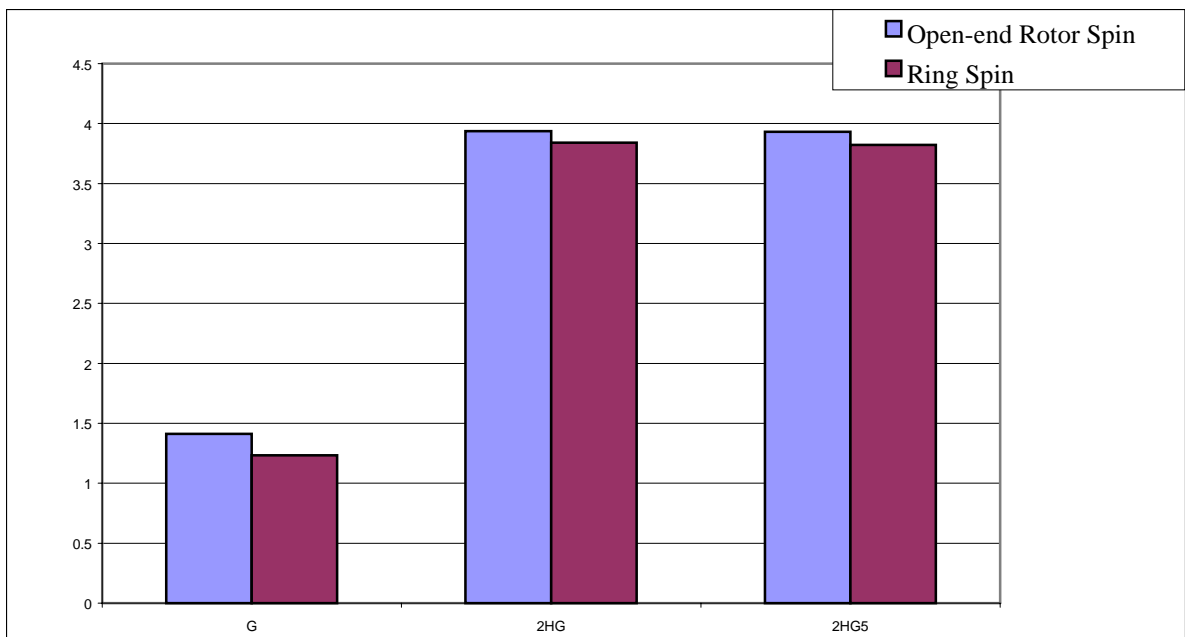


Figure 4-18 Shear Properties of Kenaf/Cotton Fabrics from Yarns with Different Spun Method

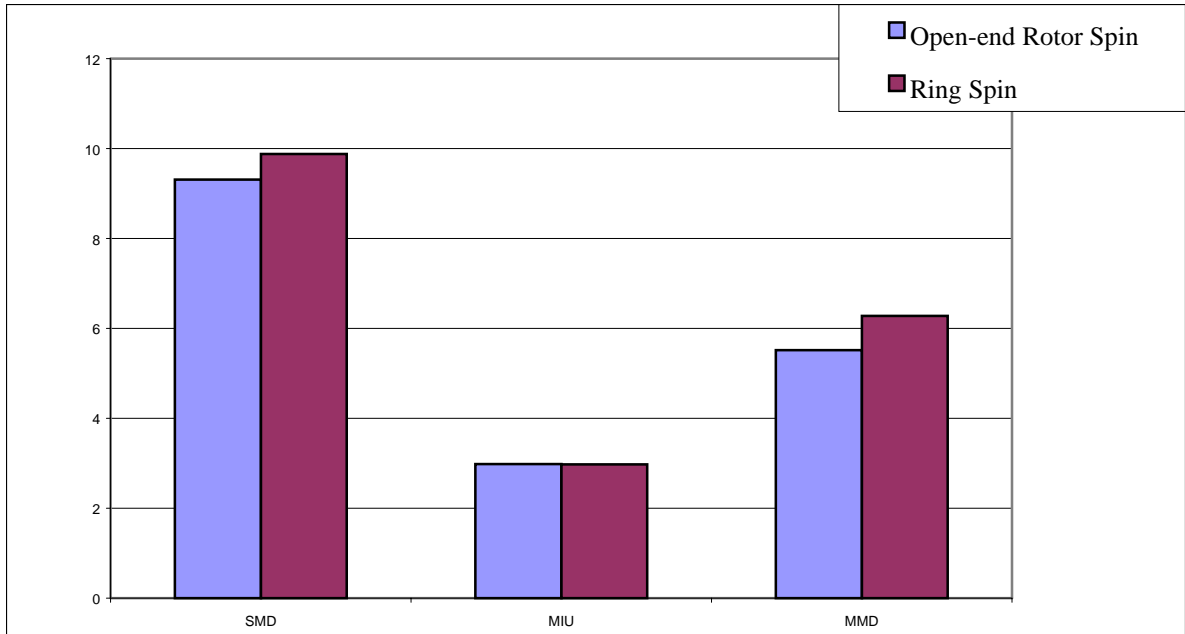


Figure 4-19 Surface Properties of Kenaf/Cotton Fabrics from Yarns with Different Spin Method

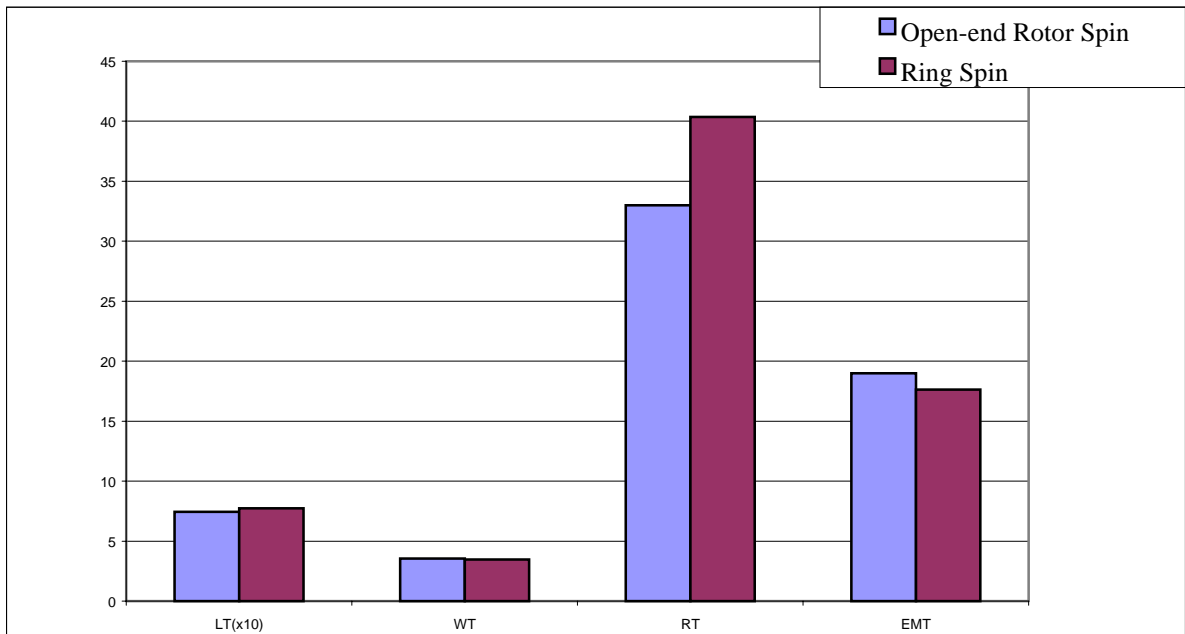


Figure 4-20 Tensile Properties of Kenaf/Cotton Fabrics from Yarns with Different Spin Method

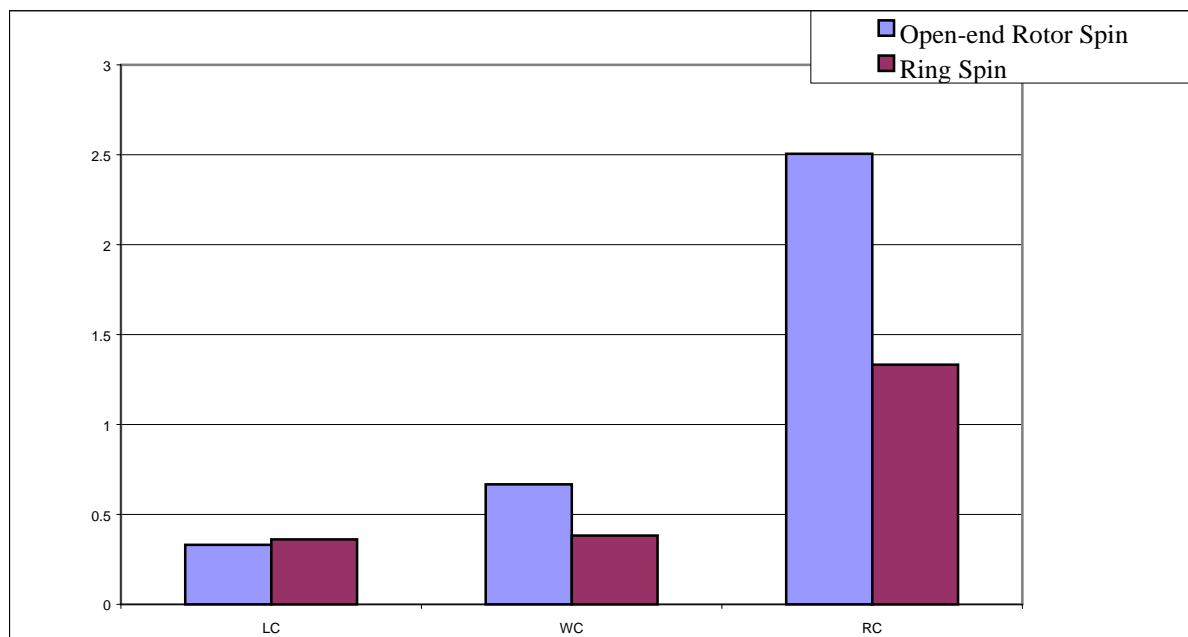


Figure 4-21 Compression Properties of Kenaf/Cotton Fabrics from Yarns with Different Spun Method

Chapter 5 Conclusions and Suggestions for Further Work

5.1 Conclusions

In response to the industry's need for developing the technology for processing kenaf fiber, this research work focused on a study of improving kenaf spinnability. The kenaf bundles were treated with the chemical reagents—NaOH and NaHSO₃ with different concentrations and different reaction time, and then softened by commercial softener. These Treated fibers were then blended with cotton to spin into yarns by Rotor spin and Ring spin. The experimental yarns were knitted into fabrics. The properties of fibers, yarns and fabrics were tested using a series of instruments.

1. After the chemical treatment, fiber fineness, softness and elongation at break were improved, but the fiber bundle strength and length were decreased. Increasing the concentration of sodium hydroxide weakened the fiber strength significantly.

2. Yarns with lower kenaf blending ratio were spun more easily. Rotor spun yarns with high kenaf content required high levels of twist, which made them have more elongation for break. But ring spun yarns were stronger. In general, the open-end rotor spun yarns appeared more uniform than the ring spun yarns and exhibited less hairy appearance.

3. Fabrics became stiffer when kenaf blending ratio was increased. The fabrics knitted from ring spun yarns were softer but weaker than those from open-end Rotor spun yarns and had more hairy appearance.

5.2 Suggestions for Further Work

1. The kenaf we treated was bought from Mississippi, it was already dried and coarsely separated. Ret from fresh kenaf may help to reduce the lignin content.

2. For the chemical treatment, we have known that high concentration of NaOH may weaken the fibers, but we do not know how it damage the fibers. If possible, the fiber structures should be observed to see how the reagents changed the fiber structure, so a better chemical retting method could be found.

3. High pressure may help the fibers to separate from each other. It would be a good idea to combine the high pressure and chemical retting together to reduce the usage of chemical reagent and extraction time.

4. Because both kenaf and cotton are cellulosic fiber, it is impossible to identify them by chemical methods. It is very helpful and necessary to find out a method to calculate the exact kenaf content in the yarns and fabrics.

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Vita

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